dom : A KNOWLEDGE BASED SYSTEM FOR ELECTRIC DISCHARGE MACHINE

by

PARTHAPRATIM DEY

ME
1993
M
DEY
EDM

TH
ME/1993/M
D53e

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

MARCH, 1993

EDM-edom : A KNOWLEDGE BASED SYSTEM FOR ELECTRIC DISCHARGE MACHINE

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

by
PARTHAPRATIM DEY

to the
DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
MARCH, 1993

26.3.93

CERTIFICATE

It is certified that the work contained in the thesis entitled, 'EDM - edom A Knowlwdge Based System for Electric Discharge Machine" by Parthapratim Dey has been carried out under my supervision and that this work has not been submitted elsewhere for a degree

(B. Sahay)

March 1993.

Professor,

Department of Mechanical Engg.

I.I.T., Kanpur.

0 3 MAY 1993
CENTRAL LIBRARY
I I T KANPUR
Acc. No. A.115684

ME-1993-M-DEY-IDM

CONTENTS

CHAPTER :: ONE

INTRODUCTION

1.1 : PREFACE

Electric Discharge Machining (EDM) belongs to 'non-traditional' machining process as it employs high energy sparks under an ionised column of dielectric fluid instead of an conventional cutting tool, But during the last few decades it has become 'conventional' in the sense that it is now a widely accepted machining process especially for 3-D shape machining Simplicity in operation, high precision achieved, and capability of machining extremely hard and brittle material (sole requirement being its electrical conductivity) have made the process an efficient as well as a popular machining technique. In many cases , low metal removal rate and high tool erosion offset the effectiveness of EDM and more seriously, restricts its large scale application. Since its introduction in the 1940s (in Russia) there has been a research thrust with the following two aims : firstly, to improve the metal rate maintaining the other desirable work-results as fine finish, high precision, etc., secondly, to restrict the tool erosion to a minimum level. Recent developments in transistorised pulse generator gives a better control over the spark discharge. Now researchers have been succeeded in reducing the tool wear to a marginal level (upto less than 1%) by carefully selecting the machine-setting parameters Improvement in met al removal performance have been reported by using trapezoidal pulses instead of rectangular pulses. (The latter is generally used .)

Some research works are aimed at getting an 'optimised' set of input parameters which are to be set on the machine to get best output parameters which describe the technological effectiveness of the process To develop an efficient adaptive control strategy to prevent unwanted arcs (which do not take part in metal removal) is another important research area in EDM. Likewise there are several other aspects of EDM in which the researchers have put their effort with an common goal to improve the machining performance of the process to give it a wider range of application.

1.2 : THE PROCESS

Here, a brief discussion on the related terminology is presented The detailed description of the spark discharge phenomenon is not discussed here as it not directly related this work.

o The R-C and controlled pulse circuit : Earlier (upto around 1960) Resistance-Capacitance spark generators were used in ED-Machines. It has the following drawbacks :

i. Major portion of the time spent on an EDM operation in charging the capacitors i e., a long idle period. Again, due to a high peak current at the instant of spark initiation the resulting temperature is much higher than that needed to remove a particle from the workpiece and thereby causing a thermal damage of the tool electrode

ii. Finer finishes were obtainable at the expense of metal removal rate.

The advent of the transistorised controlled-pulse generator resulted in a considerable improvement in metal removal performance of EDM as it offers better control over the spark

discharge The process variables frequency, pulse on and off time, peak current etc can be readily adjusted for attaining particular machining effect

- On-time : The duration of time (μs) the current is allowed to flow per cycle During this time metal erosion takes place by high energy spark discharge
- Off-time . The duration of time (μs) between the sparks (on-time) This time allows the molten metal to solidify and wash out of the arc gap (Ref fig 1 5)
- Ignition delay : A finite delay occurs between the onset of voltage pulse and formation of the resulting current pulse is known as 'ignition delay'. It is dependent upon the random effects of debris and ionisation decay within the gap, and therefore is likely to vary randomly from pulse to pulse
- Gap current : The amount of current flowing between the electrode and workpiece. This one factor determining the machining time and this can be monitored on an ammeter
- Peak current : The maximum current available from the power supply at a given setting
- Standard polarity : Standard is positive on workpiece and negative on electrode
- Servo . The system used to convert electrical signals into mechanical motion to advance or retract the electrode during the machining operation. Because a direct relationship exists between the gap volt and the spark gap, this signal is used to control the servo-system, enabling it to maintain a constant gap throughout the EDM-cycle.

- o **Spark gap** : The distance between the electrode and the workpiece during EDM There exists an 'optimum' gap which gives maximum metal removal rate
- o **Short-circuits or shorts** : This occurs when the electrode and the workpiece are in direct contact or bridged by the contaminants in the dielectric fluid
- o **Dielectric** : The fluid under which the spark gap is kept submerged always and the spark discharge takes place It insulates until required conditions between the electrode and the workpiece and then act as a conductor It also flushes the removed particles out of the spark gap.
- o **Overcut** : The clearance between the electrode and the workpiece. (ref fig 1.8)
- o **Wear ratio** · A convenient method of quantifying the wear characteristics of various electrode materials used for different applications is by a number known as wear ratio. This ratio is a comparison between the volume of the workpiece material removed versus the volume electrode material worn. Depending on the application the number can be as high as 100 : 1 for extremely low wear condition to numbers as low as 0.05 : 1 for high electrode wear combination (ref fig 1.9)

(Ref [1.1], [1.7] and [1.4])

1.3 : MACHINING FEATURES AND ADVANTAGES OF EDM

The following features are mainly responsible for its widespread acceptance :

- o It is an efficient, high precision production method of electrically conductive materials of high hardness, toughness, and varied physico-chemical properties (eg , High Speed Steels,

Carbides, Die steel, Nickel-cromium steels, Copper or alluminium alloys etc)

- o It can eliminate many intermediate steps in manufacturing process of some workpieces especially for intricate dies (Several steps like milling, drilling, boring, grinding etc can be combined into one die-sinking process in EDM. Thus it can reduce the production time.
- o Unlike the edged-tool machining EDM cuts any electrically conductive material regardless of its hardness or brittleness. Because of there is no physical contact, delicate structures can be cut successfully
- o A high degree of repeatability attained in this application facilitates a substantial saving in cost of tooling.

1.4 : APPLICATIONS OF EDM

Major application of EDM can be categorized as ·

- o Machining of ordinary through-holes and slots.
- o Complicated shape machining (eg. intricate dies in die shops) Specially for this category EDM is found to very advantageous
- o High precision drilling of microholes (eg, injector nozzle in automotive industries.)
- o Production of extremely narrow slots (width as small as 0.05 - 0.3 mm) and shallow angles, (eg, cooling channel for turbine blades in aircraft engine industry.)
- o Simultaneous drilling of a large number of holes (eg, 36 holes in single operation in a combustor of a jet engine : aircraft engine industry)

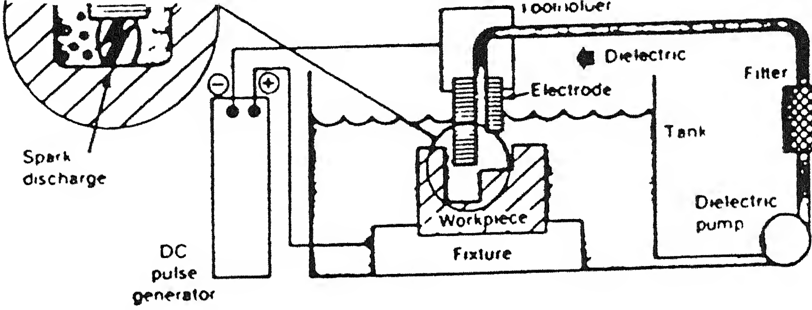


FIGURE 1 1 EDM-schematic

Source courtesy, Machining Data Handbook, Metcut Res. ref [1.14])

1 SERVO HEAD
2 MACHINE BASE
3 COORDINATION TABLE
4 DIELECTRIC TANK
5 PULSE GENERATOR

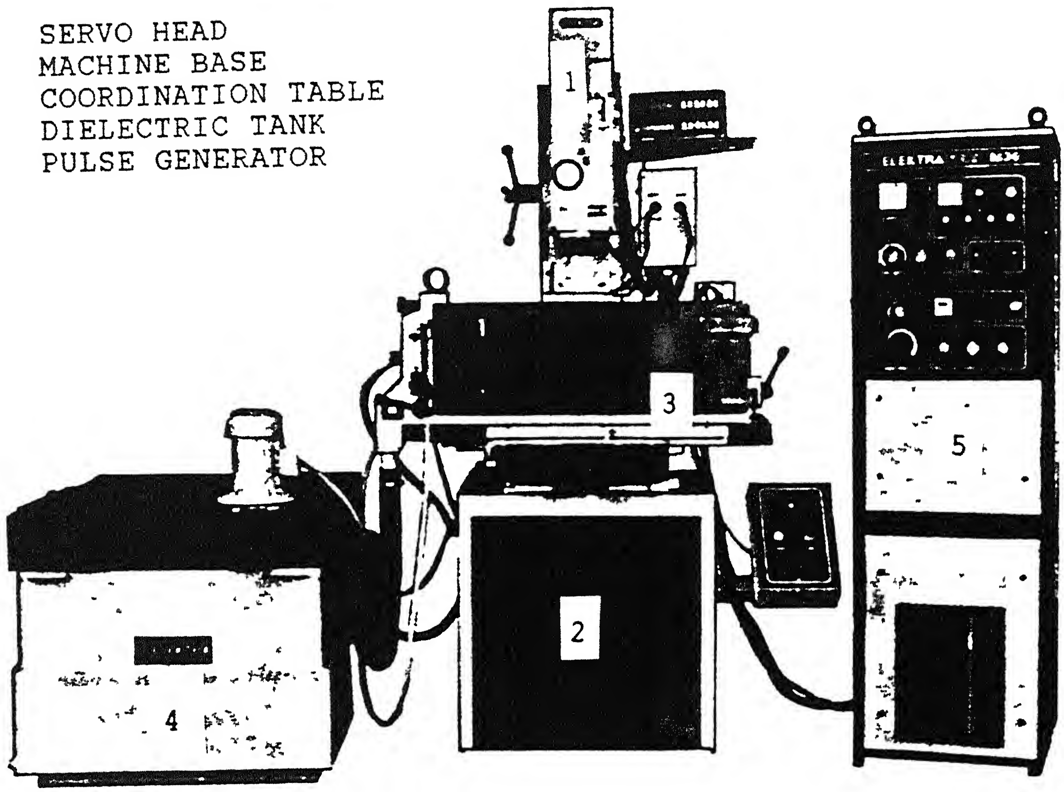


FIGURE 1.2 : The Machine

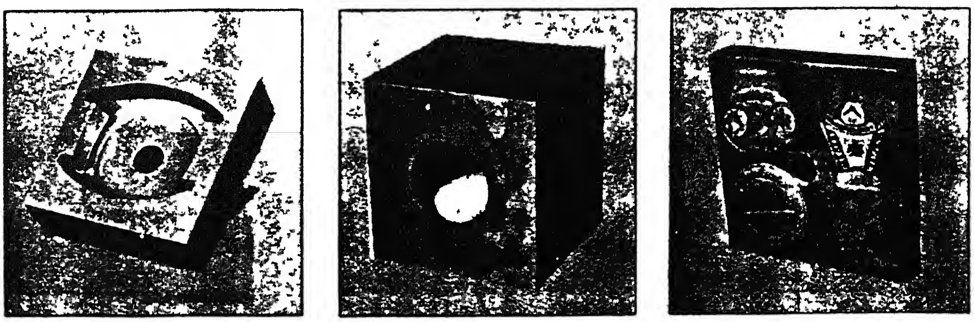


FIGURE 1 3 : Some common applications of EDM

(Source · courtesy, ELECTRONICA, Poona, India)

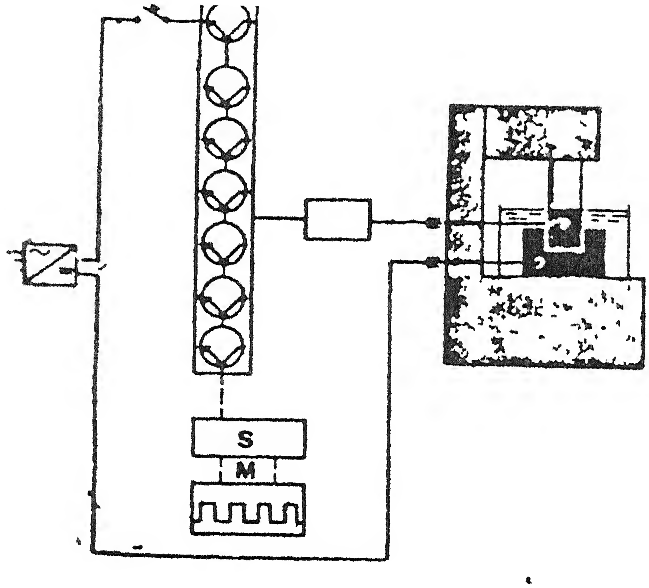


FIGURE 1.4 . The operating circuit diagram

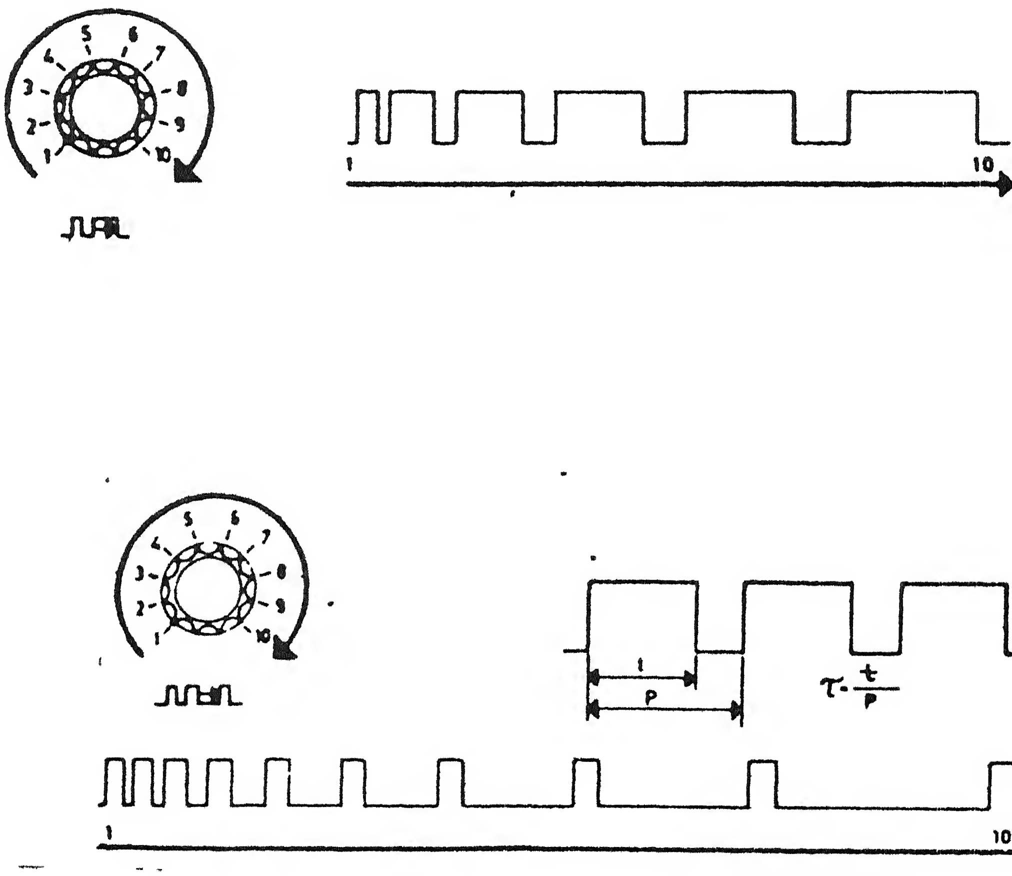


FIGURE 1.5 : Pulse on-time and off-time control
(t= on-time, p= pulse time, τ= duty factor)
(Source courtesy, Operating manual, Electra EMS, ref [1.19])

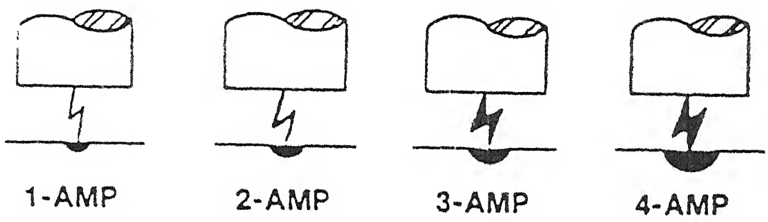


FIGURE 1.6 . Effect of current on EDM process

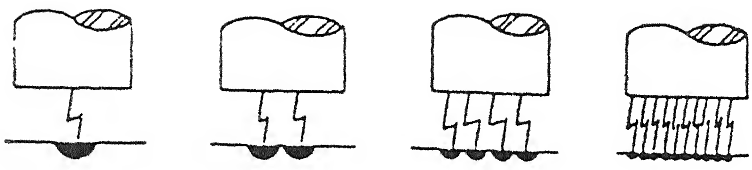


FIGURE 1 7 . Effect of frequency on surface finish

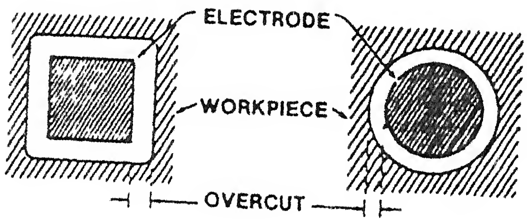


FIGURE 1 8 Overcut

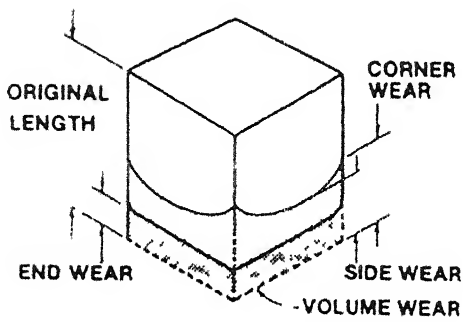


FIGURE 1 9 : Characteristics of electrode wear

Source : courtesy, Non-traditional Manu. Processes, Benedict[1.1])

1 5 EXPERT SYSTEM

Expert Systems are 'intelligent' computer program that capture the specific knowledge of a particular domain and mimic the reasoning process of human expert to accomplish tasks that normally require competent specialists for their solution Here 'intelligent' refers to Artificial Intelligence (AI) and Expert System systems are considered to be the one of the most successful application of AI Based on its functions an Expert System can be classified as being one of the following types ·

1 Interpretation System : Explain observed data by assigning some type of symbolic meaning (eg , Diesel Engine Locomotive Troubleshooting Aid .DELTA, for assisting railroad personnel in solving maintenance problems of the locomotives)
2. Prediction System : Infer likely consequences from given situation. (eg , Expert System for weather-forecasting)
3. Diagnostic System : Infer system malfunction from observed data/phenomenon (eg , the well-known Expert System for diagnosis of blood infections . MYCIN)
4. Design System : Solve or assist to solve design problems and develop configurations of objects to meet specifications and design constrains of the problem (eg , PROCON for providing assistance for design of mechanical systems.)
5. Planning System : Design a sequence of actions based on criteria and requirements (eg., Expert System for process planning in Arc Welding)

6. **Monitoring Systems** · Compare the system performance with model of expected performance (eg , Process Intelligent CONtrol, PICON for monitoring a plant operation control system where as many as 20000 control points can be accessed)
7. **Speech Recognition** . It tries to interpret spoken input (eg HEARSAY I & II)

The motivation for building Expert Systems usually consists one or more of the following .

1. to disseminate rare and costly human expertise
2. to preserve unique easily lost expertise
3. to formalise and possibly standardise expert knowledge
4. to integrate diverse source of knowledge about a problem domain and its solution methods.

The phases of Expert System life-cycle .

1. **Identification** : First problem must be identified at hand, i.e., detailed problem statement — including the goals, objective, constraints and variables associated with the problem Next one has to judge critically the nature of the problem and ways to get solution. If Expert System is found to be the most appropriate and practical solution, he can proceed to next step Otherwise, if analytical solution is readily available then this approach will be superfluous and may be, less-efficient
2. **Conceptualisation** : Key concepts and relations needed to describe the problem are explored.
3. **Formalisation** : Various prototypal problem solving

processes are to be used to model the individual problem solving components

4 Implementation . Choosing suitable implementation tool i e , suitable representational framework should be constructed

5 Testing : To put an Expert System to practical use, it must be validated by regorous evaluation of its performance. (Some conventional procedure are discussed in Chapter four)

Brief discussion on the related topics on Expert System is presented below .

o Knowledge-base : It is the very heart of any Expert System as it contains the domain specific knowledge A knowledge-base will typically contain two types of knowledge . facts and rules The facts represent the various aspects of a specific domain and are known prior to the exercise (i e., the consultation session) of the Expert System. Rules within the knowledge-base are simply the heuristics.

o Inference engine : It is the **knowledge processing** unit which carries out the reasoning task and makes the system acts like an expert. Like the knowledge-base the inference engine also contains rules and facts. However the rules and facts of knowledge-base pertain to the specific domain of expertise while the rules and facts of the inference engine more concern with the general control and search strategy employed by the Expert System in the development of a solution.

o Working memory : The results of the inference process (i.e., those that have been determined for the specific problem under

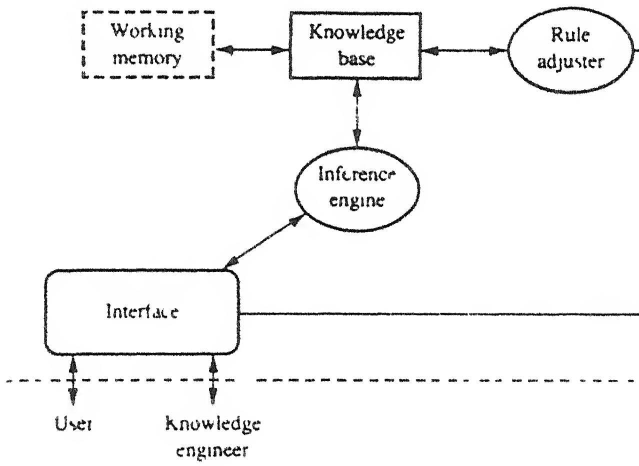


FIGURE 1.10 A generic Expert System

(Source . courtesy, Intro to Expert Systems, Ignizio [2 5])

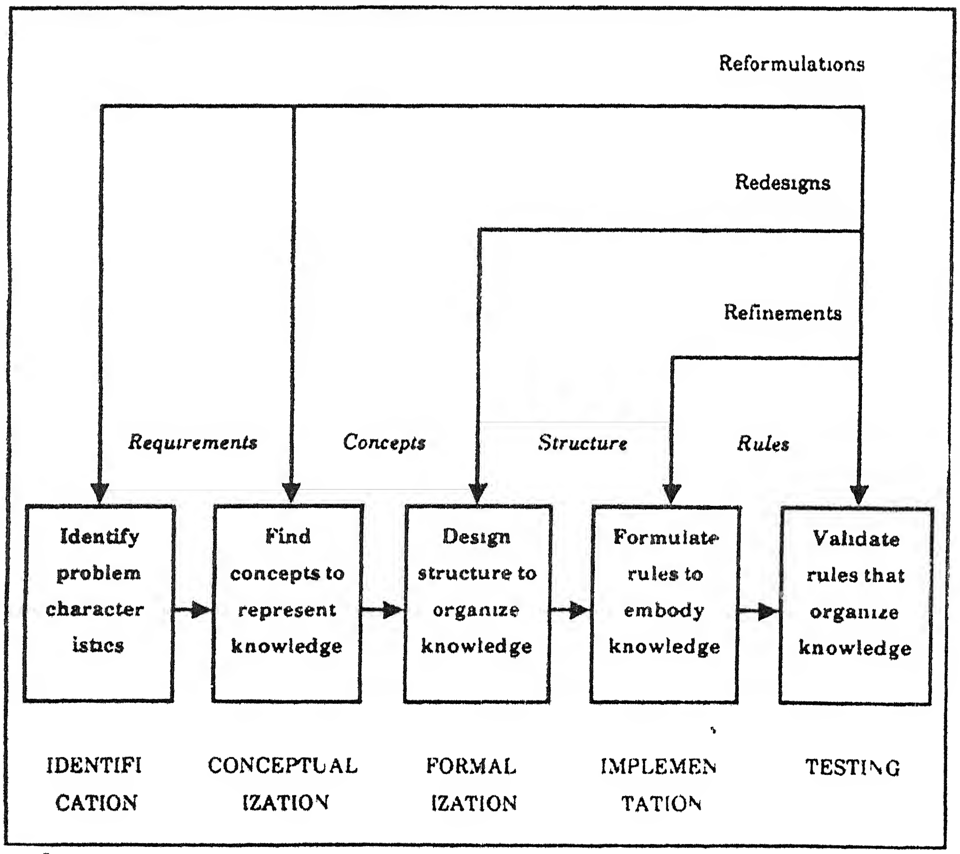


FIGURE 1.11 : Phases of Expert System development

(Source courtesy, Boose [2 3])

consideration during the consultation session) are stored in this section as 'new facts'

- **Rule adjuster** · It serves as a rule editor, i e , it enters the rules into the knowledge-base during the development phase of an Expert System This mainly concern with Experts System built on using Expert System "shells"

- **Expert System shells** : It is commercially available Expert System architecture and it has all the afore-said components minus the knowledge-base For a specific problem domain, knowledge-base is inserted into the shell-architecture by the knowledge engineers (the professionals who bridges the gap between a domain expert and the software) to make a complete system CxPERT, RuleMaster, EXSYS are well-known commercial shells

- **Heuristics and heuristic programming** : Heuristic rules or heuristics for short, are rules that are developed through intuition, experience and judgment They are often called rules of thumb For example,

  i. drive slow in a rainy day

  ii don't ask the boss for a raise if he is in bad mood.

  heuristic programming uses one or more heuristics which are combined with a procedure for deriving a solution from these rules. The main difference between a algorithmic procedure and heuristic programming, the latter tries to seek an 'acceptable' solution — one that satisfies the predetermined aspirations It may or may not be the theoretically best possible answer (i.e , optimal solution). This is why the use of heuristics can be justified only in those cases for which formal analytical

be justified only in those cases for which formal analytical methods (in particular, methods that that develop optimal solution) are not available or would prove less effective

o Knowledge representation . Knowledge representation deal with how to represent the facts and rules within the knowledge base and its major concerns are .

- to provide a format compatible with the computer
- to maintain as close as pssible a correspondence between this format and the actual facts and rules
- to establish a representation that can be easily addressed, retrieved, modified and updated
- to give a 'transperant' format, i.e., the representation scheme that can be easily read and understood by others.

Several modes of knowledge representation are proposed, some of them are discussed here in brief :

1. Object-Attribute-Value triplets (OAV-triplets) :

OAV-triplets provides the basis for the representation of the heuristic rules. Each OAV-triplet is concerned with a specific entity or object. Using the 'tool material' for EDM as an example, (i.e , the object, say copper) some of its attributes include the following :

- Melting point
- Accuracy possible (with that tool material)
- Cost

Value may be symbolic or numeric :

Melting point = 1083 $^{\circ}$ C

Accuracy possible . High

Cost : Medium

ii. Semantic network :

Semantic network may be thought as a network that is composed of multiple OAV-triplets. Unlike the OAV-triplets, semantic network are used to represent several objects and several attributes per object rather than pertaining to just one attribute for a single object

iii. Frames :

Frames is a very robust way of knowledge representation. It is useful for the design of large scale complex Expert Systems — particularly those involving a large amount of data A frame contains an object plus slots for any and all attributes, and attribute value of the particular object. In addition to the values for each attribute, slots may contain default value, pointers to other frames and sets of procedural rules. This approach is complex in nature and difficult to understand.

iv. Rulebase system :

This mode of representation become very popular because it provides a natural way of representing the 'captured' knowledge and rules in it are much 'transperent'. Such rules are are referred to as IF-THEN or production rules which are usually antecedent-consequent or premise-conclusion statements Typical rule properties include :

- Name . the name of the rule
- Premise · the IF portion
- Intermediate conclusion : the THEN portion

- Conclusion the THEN portion
- Notes notes associated with the rule
- Confidence factor a measure of confidence in conclusion of the rules and deals with the uncertainties of the domain
- Chaining preference . normal (default) mode of search technique used by the rules.
- Status either triggered or inactive for the specific problem on which the system is being applied (i e., the problem of the user)

The two fundamental search strategies employed this system are **forward and backward chaining.** Forward chaining proceeds from premises (or data) to conclusion by **pruning** the alternatives at each stage and this approach is said to be 'data-driven'. Backward chaining proceeds from a tentative conclusion backward to the premises (i.e , inputs responsible for the conclusion) It is often called 'goal-driven'

o **Knowledge acquisition :**

Knowledge acquisition is that phase of Expert System development dedicated to the identification of the rules and facts that comprises the knowledge base.

The knowledge sources that are typically available for building Expert System are :

- Human expertise : Knowledge acquisition from human expert may be accomplished through interviews in several sessions It is a very delicate task and it needs to be carefully conducted Interfacing with domain expert is often found to

be a difficult task and is some cases frustrating also (they may not wish to reveal their tricks of the trade or may mislead also) But for some problem domain human expertise is indispensable (eg Expert System for diagnostic problem MYCIN)

- Textbooks or manuals of operation detailing ant problem solving knowledge that has been already formalized
- Examples of the earlier solved cases.

Knowledge acquisition is found to be one of the difficult and time-consuming part of Expert System development and some professionals considered it as "bottleneck" of Expert System. In some cases human expert either do not exist or not available In this later instance one may either attempt to be his own expert or utilize, if possible, historical data to construct a set of production rules

1.6 : LITERATURE SURVEY

The relevant literatures are grouped under two sections : one relating to the EDM process and other relating to Expert System.

On EDM

Comparative study of different EDM tool materials is presented in [1 7], [1 14], [1 20] and [1.8].

The Machining Data Handbook from Metcut Research Association [1.14] the published works from Snoeys [1.21], Bhattacharya and El-Menshawy [1.3] gives detail analysis of the effect of machining setting on metal removal performance of EDM

The works of Feeney [1 9], De Bruyn [1 5] & [1 6], Jilani and Pandey [1 13] indicate an considerable improvement in metal removal performance of EDM using non-rectangular current pulseforms

No-wear EDM principles and graphs for parameter selection for No-wear mode is presented in [1 7] and [1 14].

Mukherjee [1 16], Srinivas [1.22], Osyczka [1 18] constructed mathematical models comprising the relationships between machine-setting variables and the desirable work results of EDM for multi-objective optimization

Gurumurthy and Anand [1 11] developed a software for selecting machining parameter for Cu-Steel system. It is developed on HP-9825 desk top computer and it gives the output in the form of a 'recommendation table'

The research works directly related to this work are discussed in detail in the subsequent chapters.

On Expert System

Alty [2.1], Rich [2.10], and Ignizio [2 5] present the Expert System building tools in detail in their works.

Taylor [2 11] gives the details of a corporative project to build a knowledge base for process planning in Arc Welding. In this work types of reasoning in its knowledge base are shown distinctly, 'shallow reasoning', which refers to the thumb rulee or simple conventional formulae used in industry , and 'deep reasoning' which uses theoretical model which facilitates more fundamental apprach.

Balachandran [2.2] discusses the role of knowledge base interfaces in Computer-Aided Design. A report on prototype development for structural engineering is included also in this work Here much emphasis is given on interactiveness and graphic

representation

Prerau [2 9] describes the features, difficulties and fundamental approach for choosing an Expert System domain

Various Expert System evaluation techniques are presented in detail by Hollnagel [2 4]

1.7 · OBJECTIVE AND MOTIVATION

EDM is very difficult to control, highly stochastic in nature, because of the complex transient nature of the spark phenomenon in the metal removal process It requires a highly skilled operator having knowledge of the multitude of the setting control of the machine required to attain some obtainable work-results A complete mathematical model comprising the relationship between the input parameters which are to be set on the machine and output parameters which describes the technological effeciveness of the process is found to be very difficult to construct for the full range of application. To control the process to achieve most of its yields now the only solution left is to apply the 'heuristics', i.e., to apply the knowledge gained from experience and trial and error on the machine

Expert Systems methodology are considered to be very suitable for such a 'less-defined' solution space and it mainly uses the heuristics as a tool which is coupled with an network to prescribe an optimized set of solution

To clarify it more, the following features of this problem domain acted as motivation to take up the new tool :

- There is a need for non-conventional approach : If some well-established parametric relationship between the critical parameters of EDM were available, then Expert System approach would have been simply superfluous
- Expertise available in the domain : In the last decades there is an research thrust on different aspects of EDM and numerous information and experimental results are published in journals, handbooks and allied publications.
- There is a need to 'capture' the expertise : Unfortunately, a 'phase-lag' is found between the successful research efforts and the manufacturing development as well as the everyday work preparation followed till now. Moreover, many of the valuable research works are in 'raw' form (with experimental data-charts and graphs) which may not be readily usable for daily operation on EDM. The is more when an expert is not accessible.
- The completed system expected to have an significant purpose : Essentially, successful 'encapsulation' of the expertise to form a good knowledge-base and an effective inference mechanism can make the system a useful software for EDM

Thus to develop an intelligent and effective computer aid for more efficient working on EDM is our goal, the knowledge-based Expert System is the approach we choose to achieve the goal.

CHAPTER:: TWO

SYSTEM SECTIONS

Expert system structures vary from one another because of their problem domain and tools (implementation language, graphic interfaces etc.) used To have an easier reasoning mechanism and faster retrieval of information or data the whole system in the present case has been segmented into six "modules", five of which has an integrated set of a database, methodology for carrying out a specific task and rules needed for correctly and effectively applying them.

<u>The modules :</u>

1. Shape families
2. Tool selection
3. Parameter selection and performance estimation
4. No-wear EDM
5. Optimum waveform selection
6. Optimization

General layout of the system structure is shown in fig 3.1 . The first module is intended only for specifying the workpiece geometry and it has no rulebase or inference engine The second and third modules, on tool and parameter selection respectively, uses these geometric parameters when they are driven. The last three modules, which deal with some special applications of EDM, can run independently. The first three interrelated modules designed to assist an operator for daily work-preparation,

process-scheduling, and performance estimation of the process.

2.1 : SHAPE FAMILIES

This section is constructed with the fundamental knowledge of 'Parts family manufacture' or 'Group Technology'. Group Technology mainly endeavours to analyse and arrange the parts spectrum and the relevant manufacturing process according to the design and machining similarity so that a basis of groups and families can be established for rationalizing the production process Now it has been recognised as powerful method for ratoinalizing small and batch production. But here this knowledge is applied to collect maximum amount of information about the workpiece in a simple way.The following 'shape families' are considered to cover the various types of surfaces produced by EDM :

1. Ordinary through-hole machining and large block size
2. Ordinary through-hole machining and small block size
3. Tapered through-holes
4. Sharp-edges cavities
5. Stepped through-holes
6. Blind dies
7. Small hole drilling
8. Narrow slots
9. Surface impressions

One important point is to be noted here that the geometric characteristics defining the type of geometry are important, but

the actual measurement may differ (the part may not be an exact 'look-alike' of the family member). The user then, has to enter other details of the shape eg , the projected machining area, taper angle, cross-sectional change through the penetration depth etc

2.2 . TOOL SELECTION

EDM can now use a number of tool material, each having specific range of applications, advantages and limitations. The following tool materials have been considered to cover a large variety :

1	Coarse-particle graphite	7.	Copper-graphite
2	Fine-particle graphite	8.	Tellurium-copper
3	Copper	9.	Copper-tungsten
4.	Brass	10.	Silver-tungsten
5.	Zinc-tin alloys	11.	Tungsten
6.	Aluminium alloys	12.	Steels

It is an expert's job to select the most appropriate tool material to meet all the requirements of the process (accuracy, surface roughness, cost, productivity etc.). Here, for this system the following four criteria are used for selecting a tool :

I. Workpiece geometry

II. Work-material

III. Surface roughness requirements

IV. Various weightages to tool-life, accuracy, cost-minimization depending upon the preference and application.

Workpiece geometry is considered as the most important factor for tool material selection. Each shape family has a separate suitability and preference to a particular tool. For example, for ordinary machining of large blocks coarse-graphite and brass are found to be more efficient than fine graphite or copper and use of costlier tools like silver-tungsten or copper-tungsten in this case is not advisable. On the other hand for sharp-edged cavities, silver-tungsten or copper-tungsten are more suitable than the others.

Work material Here 15 categories of ferrous materials (eg, high-speed steel, tool-steel, Cr-V steel etc.) and 11 categories of non-ferrous materials (eg,carbides, Ti-alloys, wrought copper alloys etc.) have been considered. Workpiece material also plays an important role in tool selection as generally each material category have different preference level for the tool materials, in many cases some tools are not recommended at all (eg. steel tools are not recommended for ferrous work materials, zinc-alloys are not used for steel workpieces). EDM is an electrothermal metal erosion process , here melting point (or solidus temperature) and heat-resistance properties are more important as compared to the strength properties. This idea gives another guideline to arrange the preference hierarchy of the tools.

Roughness requirement : The tools in the list produce different surface roughness on workpiece surfaces. For example, graphite is an sintered material and as such has certain porosity This must be taken in account when fine finish is required Coarse-particle graphite have more porosity and produce rougher surfaces The roughness requirement is shown in the following form of menu

Processing level	roughness (micron Ra)
1.Abusive(for heavy rough cut)	> 12.5
2.Roughing	6.5 - 12.5
3.Normal	3.2 - 6.5
4.Finishing	1.6 - 3 2
5.Gentle	< 1.6

Preference index for tool-life, accuracy and tooling cost · This is for final selection of an appropriate tool after fulfilling the other three requirements. In some cases several tools are found capable of fulfilling the other requirements so the preference entered here by the user will guide the system to select one tool finally For example, if copper-tungsten and fine-particle graphite are found suitable to meet the previous requirements copper-graphite will be finally selected if 'tool-life' is given preference, otherwise for cost minimization it should be the fine-particle graphite. Though the index can play a powerful role in the final selection in this way, it should be mentioned here that this preference will remain inactive if one tool is found indispensable to meet the other requirements.

For example, for small hole drilling and diameter less than 0 25 mm , tungsten-wire will be prescribed always whatever may be the other choices entered

2.3 : PARAMETER SELECTION AND PERFORMANCE ESTIMATION

It is difficult to find a set of procedure for the selection of appropriate machine setting variables (current, pulse on-time, pulse off-time, polarity) with an aim to get some desirable work-results (high metal removal rate, a predetermined level of surface roughness and overcut etc). Full range of information for parameter selection is not available except for copper-steel and graphite-steel system (copper and graphite as tools) Based on those information, specially on the experimental data charts and graphs available, (ref.[1.14],[1.7],[1.21]and fig 2.1) two separate databases are prepared for the above systems only

Geometric information and roughness requirements are the main guiding factors for selecting the machining parameters. Separate sets of rules are applied for each shape family Correlating various experimental data some parametric relations are established to form some rules. (One example is shown in the appendix).

For each of the last three shape families (namely, small-hole drilling, narrow slots, surface impressions) only an application example is shown (eg. fig. 4.7) Due to the scarcity of information , system is not provided with any database or rulebase for machining these shapes. For other shapes the procedure adopted here is given below :

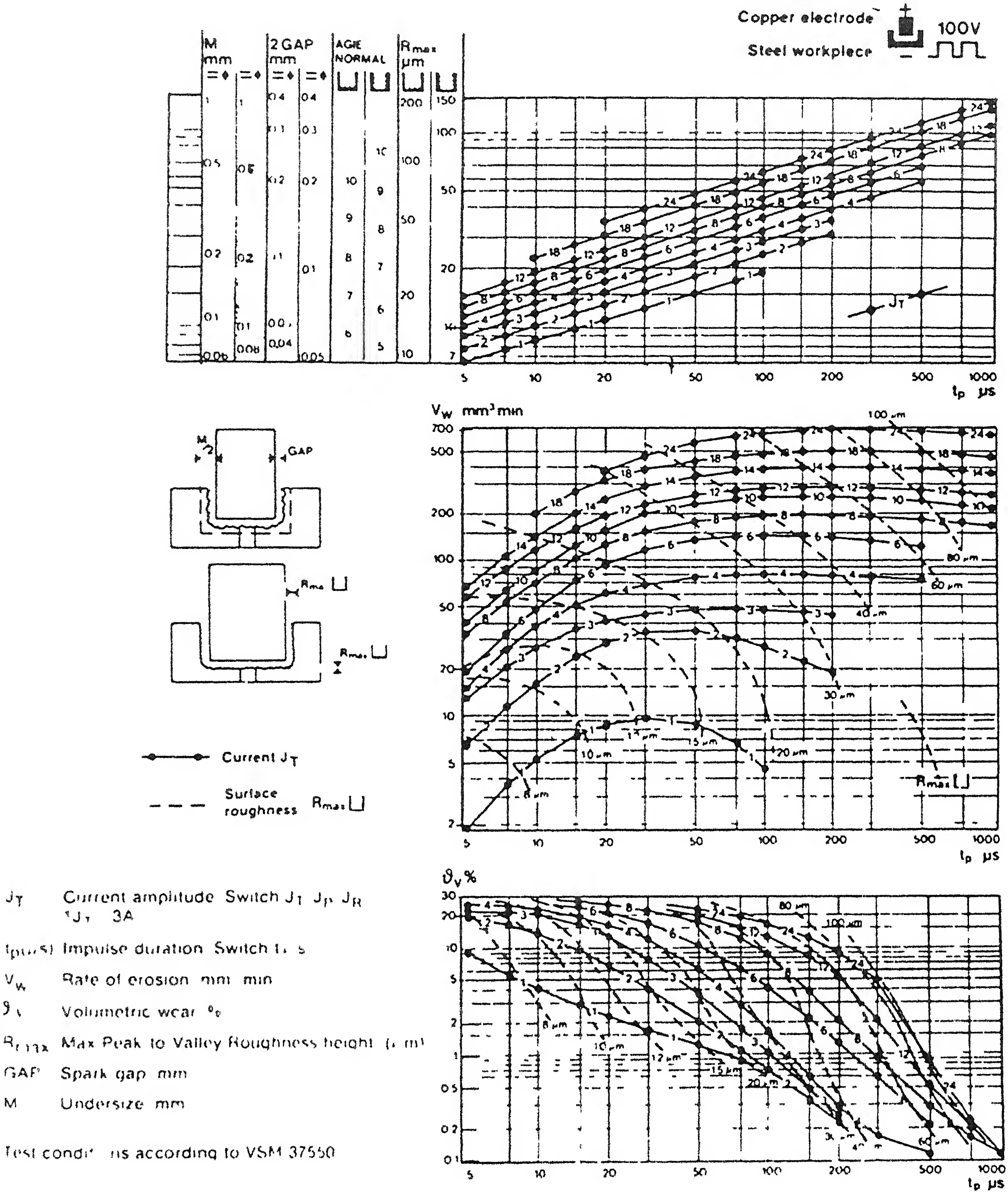


FIGURE 2 1 · The curves for parameter selection
(Source : courtesy, Machining Data Handbook [1 14])

i Based on the geometric information of the workpiece current level for roughing is fixed.

ii Experimental graphs (eg , fig 2.1) for a fixed current level show the maximum metal removal rate is obtainable at a particular set of pause on & off time. Following such experimental curves that set of pulse on & off time (for maximum metal removal rate) is chosen for roughing. It will also predict approximate overcut value.

iii.Based on either the shape of the workpiece or the permissible surface roughness, the current level for finishing is decided. For complicated shapes this current level is taken as a small fraction of the maximum current prescribed for roughing. But for ordinary through-hole machining it is the maximum current possible for the required roughness level

iv. It will also recommend the other parameters namely, polarity and open circuit voltage. If user want to machine in several stages between roughing and finishing, it will give the intermediate sets of parameters on query. For some cases,it will give additional instructions, eg. for machining tapered through-holes current at each stage should be reduced as the tool penetrates to a considerable depth.

The parameter selection module also incorporates an useful section entitled " An Final Estimation " It is important to mention here that the estimations are based on numerous experimental results given in researchers' handbook or allied publications. To get a very accurate results one has to ensure the

corresponding machining conditions (dielectric flow rate, dielectric pressure, open circuit voltage etc), which may not be possible to set in the available machine But surely they will follow the trend and there will be some percentage variation only between the estimated and the actual value.

The system will provide the following estimations on :

1 Final overcut and surface roughness

2 Machining time

3 Theoretical average power required

4 Power required at good and poor sparking conditions

o Final overcut and roughness are supplied from the database

o Machining time is calculated by dividing the volume of the material to be removed (to be supplied by the user) by the metal removal rate.

o For computing the average power consumption the following relationships are used. (ref [1.4])

$$f_{pc} = 1 /(t_f + t_o + t_d) \quad \ldots(2.3.a)$$

$$f_c = 1 /(t_f + t_o) \quad \ldots(2.3.b)$$

$$P_{theoretical} = i_f \cdot u_f \cdot t_f \quad f_{pc} \quad \ldots(2.3.c)$$

$$P_{actual} = P_{theoretical} - \gamma_{is} \cdot i_f \cdot u_f \cdot t_f \cdot f_c \quad \ldots(2.3.d)$$

Here,

t_f = pulse on-time (micro-sec)

t_o = pulse off-time (micro-sec)

t_d = ignition delay time(micro-sec), though it has very random variation in magnitude, it is taken here as a fraction of pulse on-time for simplicity, observing various experimental results.

γ_{1s} = relative frequency of the short-circuit pulses (a fraction) The fraction of total elapsed time occupied by short-circuit condition is on average γ_{1s} . For an approximate calculation it is taken here as 0.10 for good sparking condition and 0.60 for poor sparking condition.

f_{pc} = mean current pulse frequency.

f_c = frequency for short-circuit pulses. For short-circuit pulses there can be no 'ignition delay' i.e., $t_d = 0$.

Here it may be mentioned that by measuring the average power 'externally' from energy balance (not indirectly by using the values of current,voltage etc.) an then comparing it with the average power computed as above, we can think of a simple data-dependent adaptive control system for preventing short-circuit pulses.

2.3 : OPTIMUM WAVEFORM SELECTION

Comparison of the performance of the different pulse waveforms shows that :

- o Reduction in relative electrode wear upto three times can be achieved if trapezoidal or sloped pulses are used in place of rectangular pulses in some cases, though the latter is generally used in modern machines. It is argued that the plasma channel diameter is very small at the initial stage of the discharge and it gradually increases throughout the discharge time. For rectangular pulses current density as well as energy density is high during the early stage of the discharge. Investigation show that most of the tool electrode erosion occurs during first few micro-seconds of the pulse. Trapezoidal pulses are characterised by increasing the current amplitude linearly throughout the pulse duration with small initial current amplitude. These pulses will give a more 'even' distribution of pulse energy as the plasma channel expands.(Ref [1.9],[1.13],[1.5])
- o Step pulses, having lower current level for approximately half of the discharge time and higher for the rest, also yield a better volumetric wear ratio and are specially advantageous for long pulses.(Ref [1.9] & [1.13])
- o Distinct improvement in machining performance is found only in semi-finishing region. Virtually, no advantage to be gained with sloped pulses below 30 micro-sec pulse on-time. For long pulses, advantages of sloped pulses becomes marginal as the wear-ratio is already very low in that region for rectangul pulses. (Ref [1.9])

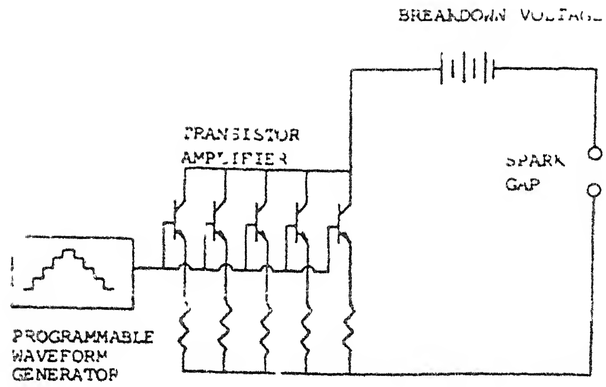


FIGURE 2.2 : Circuit diagram with Programmable Waveform Generator
(Source : courtesy, ref [1.9])

WORKPIECE MATERIAL	- DIE STEEL [illegible]
ELECTRODE MATERIAL	- COPPER
ELECTRODE POTENTIAL	- POSITIVE
PULSE DURATION	50 µSec
PULSE PAUSE	- 150 µSec
LIFT CYCLE	50 CYCLES PER MINUTE
NOMINAL GAP IONIZATION VOLTAGE	- 25v

TEST REFERENCE	CURRENT WAVESHAPE (Ordinates in Amps)	PULSE ENERGY (mJ)	WORKPIECE MATERIAL REMOVED PER PULSE mm³ × 10⁻⁶	VOLUMETRIC WEAR RATIO %	SURFACE FINISH VDI MEASUREMENT µm
G	10	12 7	1[illegible] 4	3 [illegible]	4 5
H	8, 1[illegible]	1[illegible] [illegible]	1[illegible] [illegible]	[illegible] 45	5 0
J	6, 14	1[illegible] 9	1[illegible] 0	1 [illegible]	[illegible]
K	4, 16	12 9	29 0	6	[illegible] 0
L	6, 12, 15µS	12 6	[illegible] 0	[illegible] 93	5 0
M	12, 8	12 7	40 3	4 59	5 0
N	16, 4	12 8	5[illegible] 1	10 1	5 0
P	6, 14, 25µS	12 5	36 4	1 93	5 0
Q	12	15 0	53 4	4 3	5 0
R	[illegible], 16	15 0	48 5	2 19	5 5

FIGURE 2.3 : One set of tests with trapezoidal and stepped current pulse forms

- It is found that, for pulses of a given energy, surface finish is not much dependent upon pulse shape.(Ref [1 9])
- It has been found that the average height of the trapezoidal pulses, giving the same removal rate as rectangular pulses of the same length, is about 75% of the height of the rectangular pulses. (Ref [1.6])
- All the afore-said results are proved for copper-steel system only.
- A commercially available programmable waveform generator (PWG) can be connected to get various wave shapes, which are to be fed to the spark gap by a parallel bank of power transistors.(Ref [1.9])

This part of the system is mainly intended for EDM manufacturers and researchers . Based on the available research works (mentioned above), two different strategies have been developed for roughing and semi-finishing. The goal of the system is to select the slope value of the optimum waveform for an 'eqivalent' rectangular pulse. To clarify, an 'optimum' trapezoidal pulseform is that particular pulse which produce best metal removal performance at a fixed pulse on-time level. Here, the term 'eqivalent pulses' does not mean the iso-energic pulses but the pulses giving same removal rate with same pulse length.

Interpolating the various experimental data-points by linear functions of the parameters - current, pulse width and slope it was found that the functions give rise to a simple but powerful selection strategy for roughing.

As sloped pulses have major advantage during semi-finishing, it needs very accurate value of the slope in that region Instead of interpolating functions an array is used to store the accurate values of slope and other allied parameters for defining the sloped and equivalent rectangular pulse for the semifinishing region. Thus the error due to interpolation over a large range is minimised. A tree-structure of if-then rules controls the entire selection process (discussed in chapter 3). The example (and fig 4.9) shown in the corresponding section in chapter 4 can clarify the process more.

2.5 : NO-WEAR EDM

The salient points of no-wear EDM are as follows :

- o No-wear EDM is a mode of operation in which the electrode wear is virtually eliminated and the term is generally applied to cases in which electrode to workpiece wear-ratio is 1% or less.
- o Recent developments in pulse-type power generator give greater control over arc discharge because of its ability to control the pulse-width (arc duration). This has widen the range of application of No-wear EDM.
- o Reverse polarity (i.e., tool-electrode positive and workpiece negative) is essential for this mode of operation.
- o The most common combination for no-wear is that of copper or graphite as tool and steel as workpiece. Silver-steel, copper-aluminium and graphite-aluminium are also reported to demonstrate no-wear mode, but they are less common. Brass and copper-graphite, the widely used tools in EDM, are not capable

of operating in the no-wear mode.

- For no-wear, machine-setting variables are controlled in such a way that it maximizes the melting depth on workpiece while holding that of the electrode to some lesser value.
- By numerous experimentations researchers have developed some technological curves (ref. fig 2.3) which are now used to control the parameters for no-wear mode.

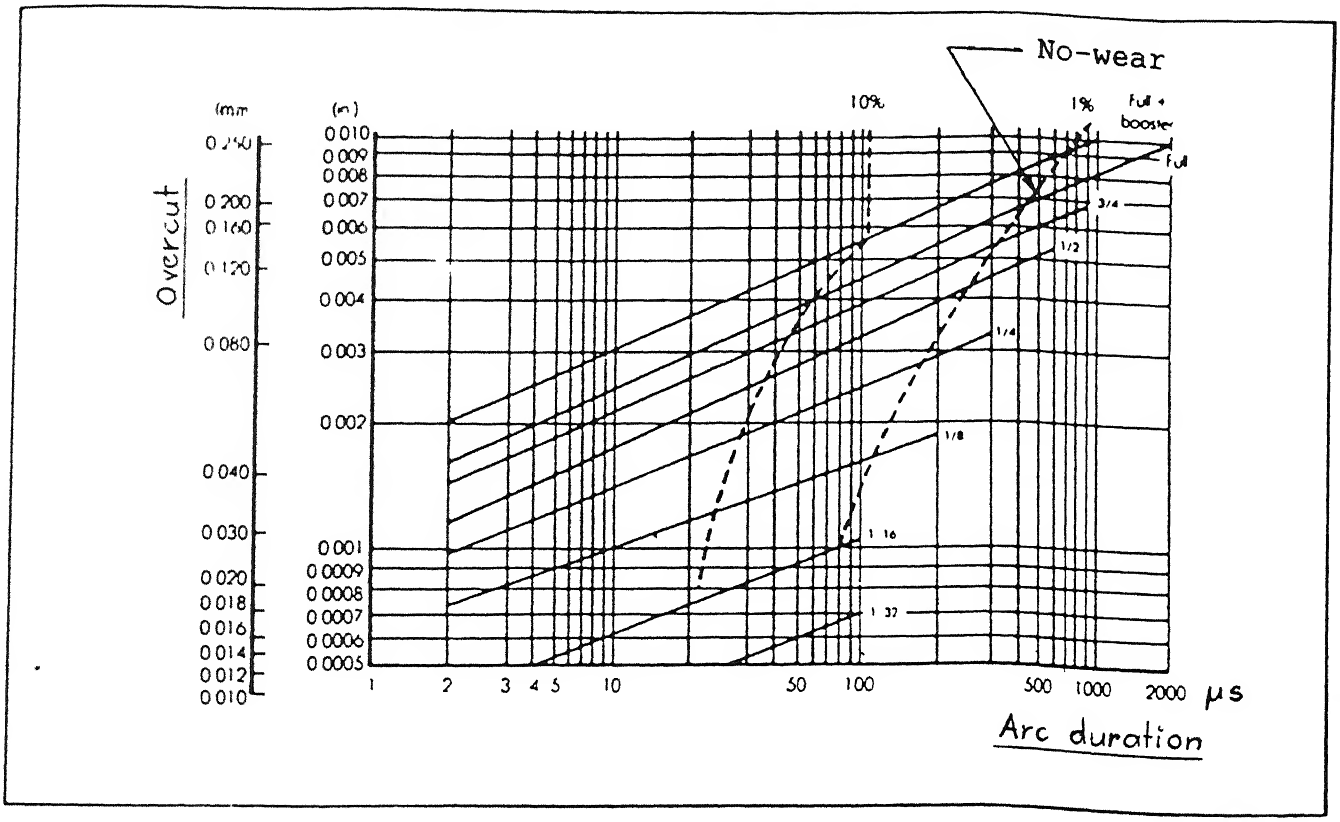
(Ref [1.7])

2.5.1 : APPLICATIONS OF NO-WEAR EDM

- No-wear EDM is genarally applicable to jobs requiring complicated or costly tools. Conventional EDM gives higher metal removal rate but this is often offset by the decrease in tool-life. When the time spent in replacing and redressing the tool is considerable then No-wear EDM is definitely advantageous . For high production, multiple-electrode jobs it has limited use.
- Contrary to the prevailing misconception, No-wear EDM is found suitable also for fine finish (around 1.27-2.54 μm) and smaller surface area (electrode surface area as small as 3.2 mm^2).

This Expert System is an attempt to guide the user for both copper-steel and graphite-steel systems through the following sequential steps :

i. Highest peak current at which the cut can be started is calculated on the basis of the geometric information of the workpiece. Here for generalisation, the projected area of the end of the electrode is considered as the current-density is maximum at the beginning of the cut.



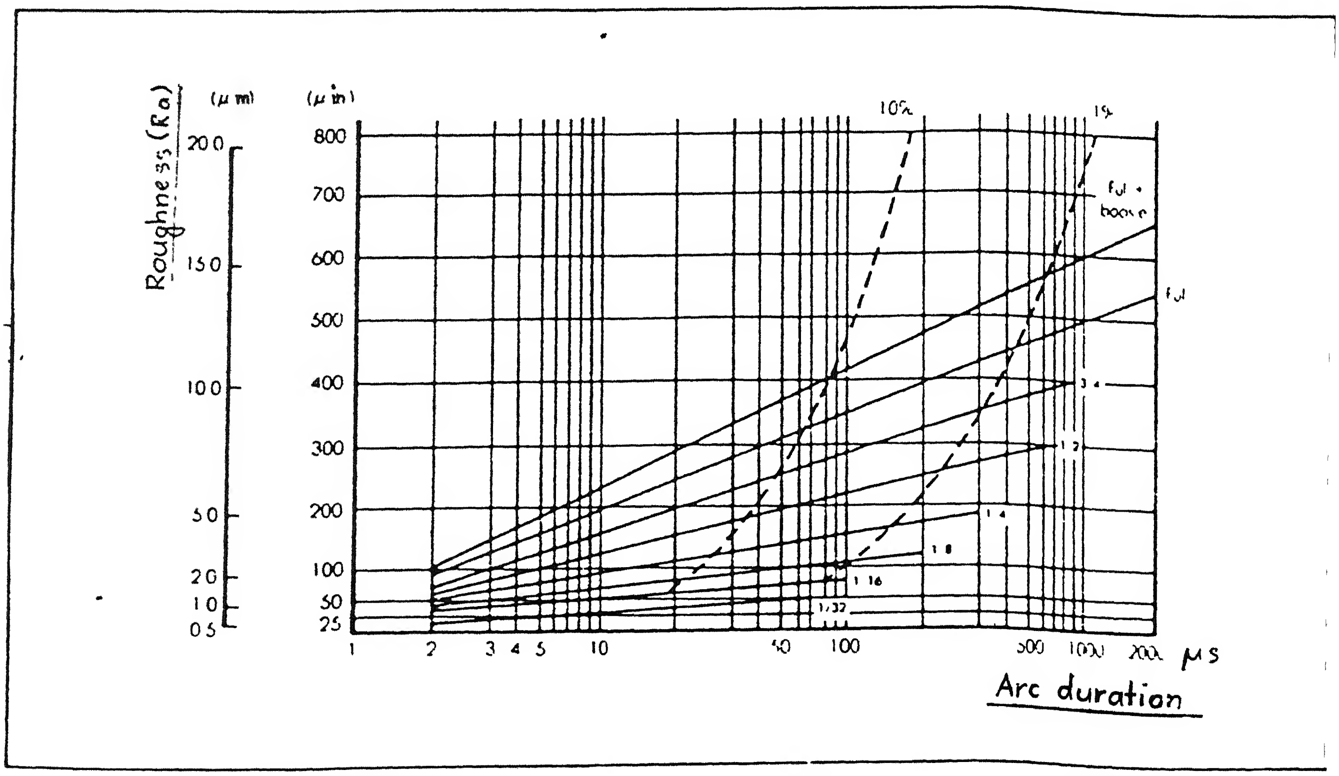


FIGURE 2.4 . Curves for No-wear EDM

(Source courtesy, Drozda [1 7])

ii Maintaining this peak current level, cut should be proceeded as deep as possible with allowance for overcut (The value of the overcut will be supplied by the expert system).

iii Final surface roughness requirement of the user will determine the peak current level at which last cut must be made.

iv Once the upper and lower current levels are fixed, current is to be reduced gradually from the peak current level to the lower level. For the current level at each stage pulse on time and overcut values will be supplied. The process should be continued in this manner till the required finish is obtained

2.6 : OPTIMIZATION

A mathematical model of EDM will definitely involve numerous parameters and a complete model seems to be very difficult impossible still now. Researchers generally choose a particular aspect of EDM and try to construct a mathematical model for optimization on that. For optimization of EDM, the steps followed by them are given in sequence :

1. Establish the parametric model of the problem comprising some relationships between the process parameters (current, on-time etc.) and desirable work results (surface finish, overcut etc.) This is achieved usually by correlating the experimental data by using regression analysis etc.

ii Formulation of the optimization problem by selecting proper objective function and the constraints of the process Essentially, thereafter the model gets intertwined with the practical aspects of the problem

iii Solve the optimization problem by any suitable computational technique

Three such models were chosen and are solved by similar algorithms to impart a powerful decision-making capability to the system. (Detailed discussion on the algorithm is given in chapter 3 and some results are presented in chapter 4)

2 6.1 . Model - one

This model has the interrelationship between principal performances indices and significant process variables as shown shown below . (Ref[1.16])

Objective function ::

$$MRR = 1.8889 \times 10^{-4} \quad w^{1.5138} \quad f^{0.4599}$$

MRR = Material Removal Rate (mm^3/min)

Variables .

1. Pulse width (μs) = w
2. Frequency (kHz) = f

Constraints ::

$$EWR = 5.5142 \times 10^{-4} \cdot w^{1.5719} \cdot f^{0.3636}$$

$$MRR/EWR = 3.4255 \times w^{-0.0581} \cdot f^{0.09962}$$

$$H = 0.5469 \times w^{0.6283}$$

where, EWR = Electrode (Tool) Wear Rate (mm^3/min)

MRR/EWR = Volumetric wear ratio

H = Maximum height of surface roughness (micron)

The optimization problem :·

Maximize MRR

Subject to the bounds :.

$$l_1 \le w \le u_1$$

$$l_2 \le f \le u_2$$

and the general constraints .

$$-L \le EWR \le u_3$$

$$l_3 \le MRR/EWR \le U$$

where, l_i and u_i are the limits to be set by the user

L , U are big positive numbers

2.6.2 : Model-two

In this model, the measure of the performance of the process like MRR, surface finish etc. are assumed to be functions of tool-dia, depth of penetration, and on-time (Ref[1.22])

Objective function ::

$$MRR = 34.536 \times D^{0.410} \; d^{-0.014} \; t^{-0.483} \; e^{0.007t}$$

MRR = Material Removal Rate (mg/min)

Variables ::

1 Tool Diam = D (mm)

2. Depth of Penetration = d (mm)

3 On-time = t (μs)

Constraints ::

1. $OC = 0.0159 \; D^{0.524} \; d^{-0.031} \; t^{0.020} \; e^{0.002t}$

2. $SR = 1.159 \; D^{-0.088} \; d^{0.031} \; t^{0.282} \; e^{-0.001t}$

3. $REW = 4225.95 \; D^{0.901} \; d^{-0.014} \; t^{-1.099} \; e^{0.007t}$

4. $TWR = 641.62 \; D^{-0.085} \; d^{-0.164} \; t^{-1.499} \; e^{0.014t}$

where, OC = Overcut (mm)

where, OC = Overcut (mm)

SR = Surface Roughness (microns)

REW = Relative Electrode Wear (%)

TWR = Tool Wear Rate (mg/min)

The optimization problem ::

Maximize .: MRR

Subject to the bounds ::

$$l_1 \le D \le u_1$$

$$l_2 \le d \le u_2$$

$$l_3 \le t \le u_3$$

and the general constraints .:

$$-L \le OC \le u_4$$

$$-L \le SR \le u_5$$

$$-L \le REW \le u_6$$

$$-L \le TWR \le u_7$$

where, l_i and u_1 are the lower and upper bounds to be given by the user; L is a large positive number.

2.6.3 : Model-three

This model for multi-criteria optimization is also developed with the aim to improve the performance of the process by optimizing the machine-setting variables like on-time current etc. to give the best possible results about the yields like the first model. This model involves more parameters than the first model but it is applicable to certain range of the the machine setting parameters (Ref[1.22])

Objective function .

$$MRR = 43\ I^{1.0116}\ t_i^{0.062}\ t_o^{-0.092}\ D^{0.51}\ d^{0.028}\ (mm^3/min)$$

Variables .

1 Discharge current (A) = I

2. Pulse duration (μs) = t_i

3. Pulse interval time (μs) = t_o

4. Erosion diameter (mm) = D

5 Erosion depth (mm) = d

Constraints ::

1 $EW = 6.115\ I^{2.312}\ t_i^{-1.613}\ t_o^{0.355}\ D^{-0.538}\ d^{-0.191}$

2 $SR = 5.341\ I^{0.264}\ t^{0.108}\ t^{0.012}\ D^{0.007}\ d^{-0.20}$

3 $P = 91.75\ I^{0.943}\ t^{0.132}\ t^{-0.119}\ D^{-0.174}\ d^{0.04}$

where, EW = Electrode Wear (%), SR = Surface roughness (micron Ra), P = Power consumed by the machine (W)

The optimization problem ::

Maximize :: MRR

Subject to the bounds ::

$l_1 \le I \le u_1$ $\qquad$ $l_2 \le t \le u_2$

$l_3 \le t \le u_3$ $\qquad$ $l_4 \le D \le u_4$

$l_5 \le d \le u_5$

and the general constraints ::

$-L \le EW \le u_6$

$-L \le SR \le u_7$

$-L \le P \le u_8$

l_i , u_i , L have the same meaning as before

NB : To test the algorithm, an simple optimization problem on EDM using RC-circuit (ref[1.2]) was tried and it was found to give accurate results but that problem is not included here.

2.7 : SUMMARY

This chapter mainly presents the 'raw material', the extracted expertise from the related research works, used for the Expert System. It is discussed under several sections each corresponds to a module of the system.

The first section deals with the geometric information using some basic idea of Group Technology.

The second and third sections, on tool and parameter selection respectively, narrate the selection procedures using the geometric information.

The fourth section presents a comparative performance study of different waveforms and the procedure for 'optimum' waveform selection.

The fifth section discusses the theory and application of No-wear EDM and then clarifies the procedure followed here to guide the user to control machine setting variables for No-wear.

Three mathematical models for optimization are presented in the last section.

CHAPTER :: THREE

SYSTEM STRUCTURE

The system is built in ANSI C on HP-Superworkstation (HP-98730) using Starbase Graphics. To have a self-explanatory and picturesque representation and for a good user-interface, knowledge of Computer Graphics relating to transformation matrix stack, windowing and clipping, double-buffering, animation is used. By removing the ANSI features of C and replacing the graphical representation by textural ones the Expert System can be made PC-compatible

It has a good explanation and dialogue facility and the part of the screen is always meant for this. A considerable amount of textural representation is provided firstly to give necessary information to the user for a menu-choice at each step,and secondly, to clarify him how a decision is being made.

It uses a large number of command statements in the program and the name of the functions and structures are given in such a way that others can modify it if necessary. This may be not that important for a conventional program.

As stated earlier the entire system is divided into si modules, first of which is only intended for collecting geometri information and the others are on five problem domain of EDM, eacl having its separate knowledge-base, rule-base, and inferenc engine. Here it should pointed out that type of segregate structure differs from that of a conventional Expert System Usually, the latter, built on using commercially available Exper

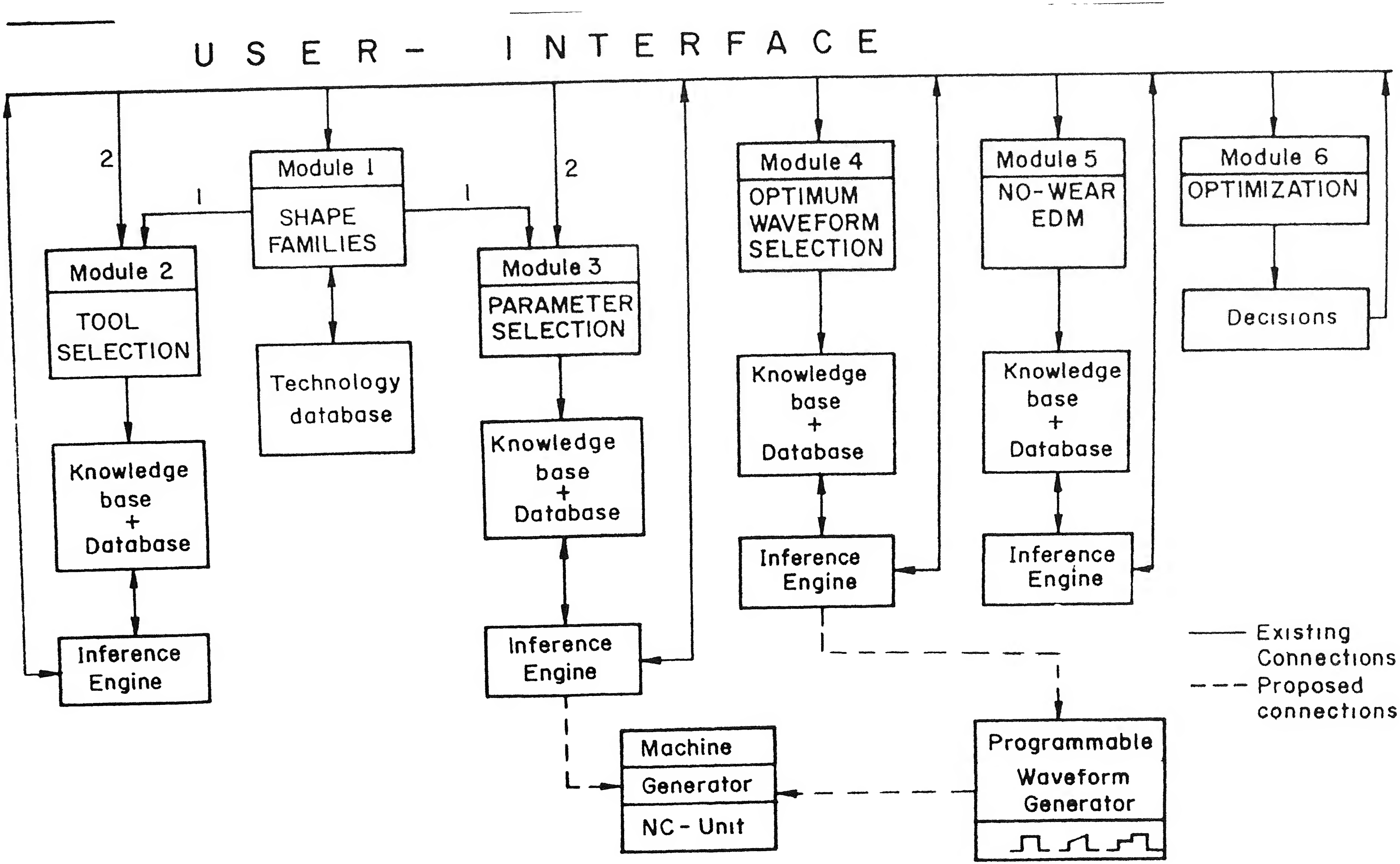


Figure 3.1 The system architecture

System "shells" have separate modules for knowledge-base, inference engine etc.

Out of the various forms of knowledge representation (frames, semantic network etc.) the rule-base system was conceived to be the most suitable for this problem domain and the implementation language

Detail architecture of the different modules of the system are presented below :

3.1 : MODULE - ONE :: SHAPE FAMILIES

Various surfaces produced by EDM were grouped into nine 'families' which are depicted in the form of a menu (ref fig 4 2 & 4 3) After choosing a particular member user will be asked to specify the other geometric information This section has no rule-base or inference engine and it can be considered as an integrated part of second or third module.

3.2 : MODULE - TWO :: TOOL SELECTION

A new approach was taken for knowledge representation in this section, which is equivalent to 4-stage chaining rule-base containing over a thousand rule. The approach can be claimed to be a powerful way of knowledge representation for such type of selection problems as it can reduce the volume (bytespace) of the of the program as well as the computational time drastically The approach can be termed as 'Eqivalent rule-base system' and it is much similar to the relative grading system for the students in a university. (The Equivalent rulebase system is shown in fig 3.2) The "candidates" (here the tools) are graded in different

"subjects" (attributes) and finally the "candidate" with maximum performance index is selected It is not at all arbitrary as it seems that the candidates are graded first and then selected As the expert is supposed to know all the outcomes (final selections) for all possible combinations, the task for knowledge representation is just the reverse, first the candidates are to be selected then graded. So as far as the number of combinations or rules are concerned the amount of task remains the same, but once it has been worked out in paper, a multi-dimensional array will be enough to store them

But for a problem domain with a large number of uncertainties, the afore-said approach may not be possible. There the candidates are to be graded first with utmost care and finally rigorous performance evaluation of the system is needed before implementation

Here two more points need to be mentioned to complete the idea **Firstly**, the 'short-cuts', if a candidate is found indispensable to meet a particular requirement, its selection can be ensured by putting a large number ("grade") for it For example, for small-hole drilling with diam less than 0.25 mm tungsten-wire will be selected always whatever may by the further choices entered **Secondly**, to make the system fully deterministic the preference criterion between tool-life, accuracy and tooling cost was introduced As stated earlier, on this basis one tool will be selected finally from the tools all of which are found fulfilling the other criteria. So this preference acts as a 'confidence factor' for a candidate to remove the uncertainty from the selection process.

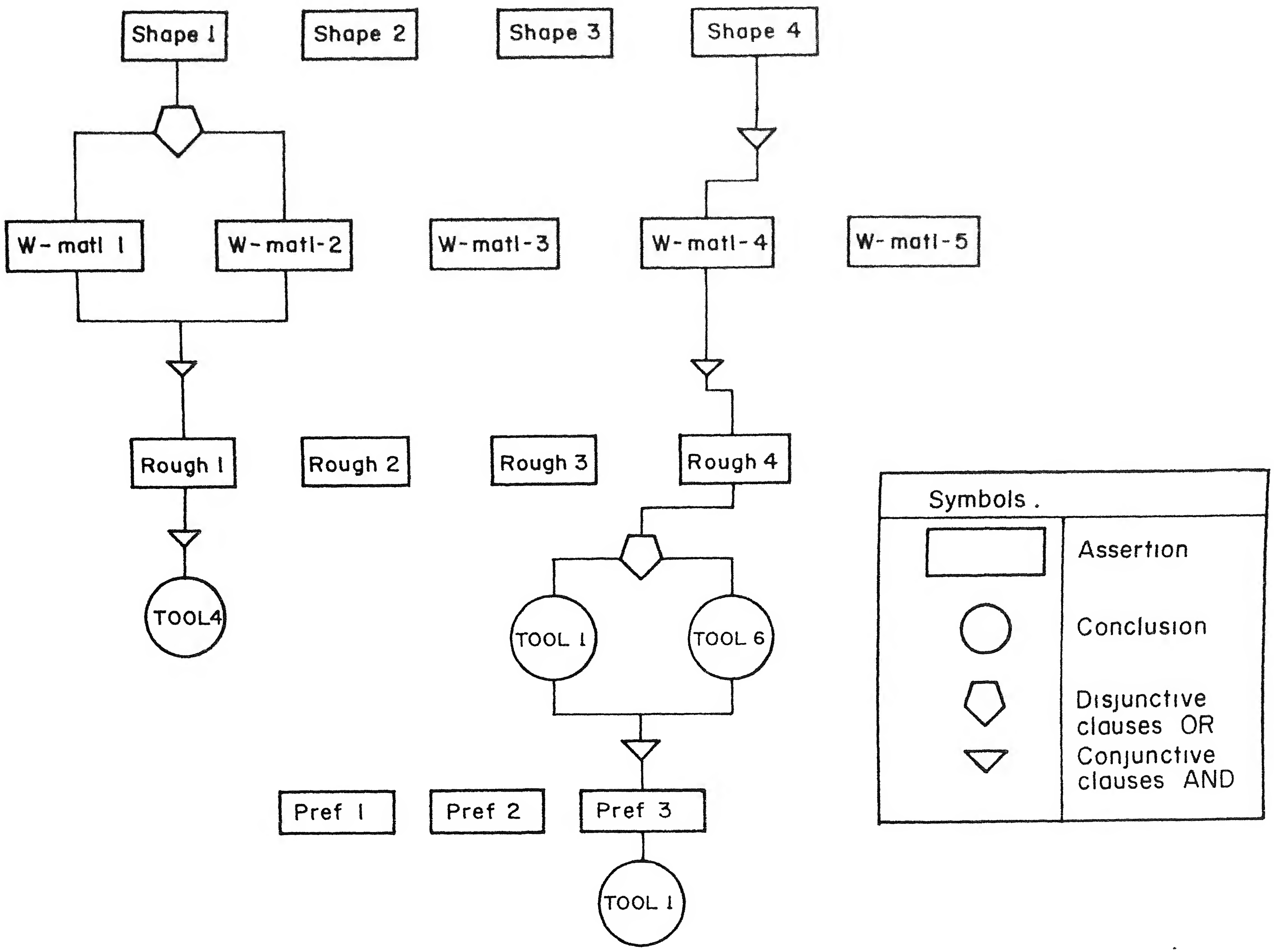


Fig 3 2 The equivalent rulebase system Inference network for tool selection (2 Rules are shown here)

3.3 : MODULE - THREE :: PARAMETER SELECTION

The knowledge acquisition of this section was made from relevant literatures which includes published papers, researchers' handbook, manufacturers' manuals and publications. (Ref [1 14],[1 17],[1.11] and [1.7])

Database was prepared from the technological curves available in the researchers' handbook ([1.14]) and by a careful study of the various experimental results published in the papers and the application examples shown in the handbooks. The knowledge base of this section has only two-stage chaining of if-then rules but the database provided is considerably large. The flow of control in this module, in brief, is as follows :

i. As soon as the shape family is chosen, inference engine triggers the set of rules meant for that shape family.

ii. The above set of rules will use the geometric parameters (eg. projected machining area, sharpness etc) to fix the roughing current level.

iii. The database stores numerous set of machine-setting parameters and their probable yields (roughness, overcut etc.). The knowledge-base searches an appropriate set of parameter for roughing from the database for the specified workpiece geometry with an aim to maximize metal removal rate.

iv. The knowledge-base then selects another set of parameters for finishingwhich can meet the other requirements of the job.

v. Based on these values the final estimation section

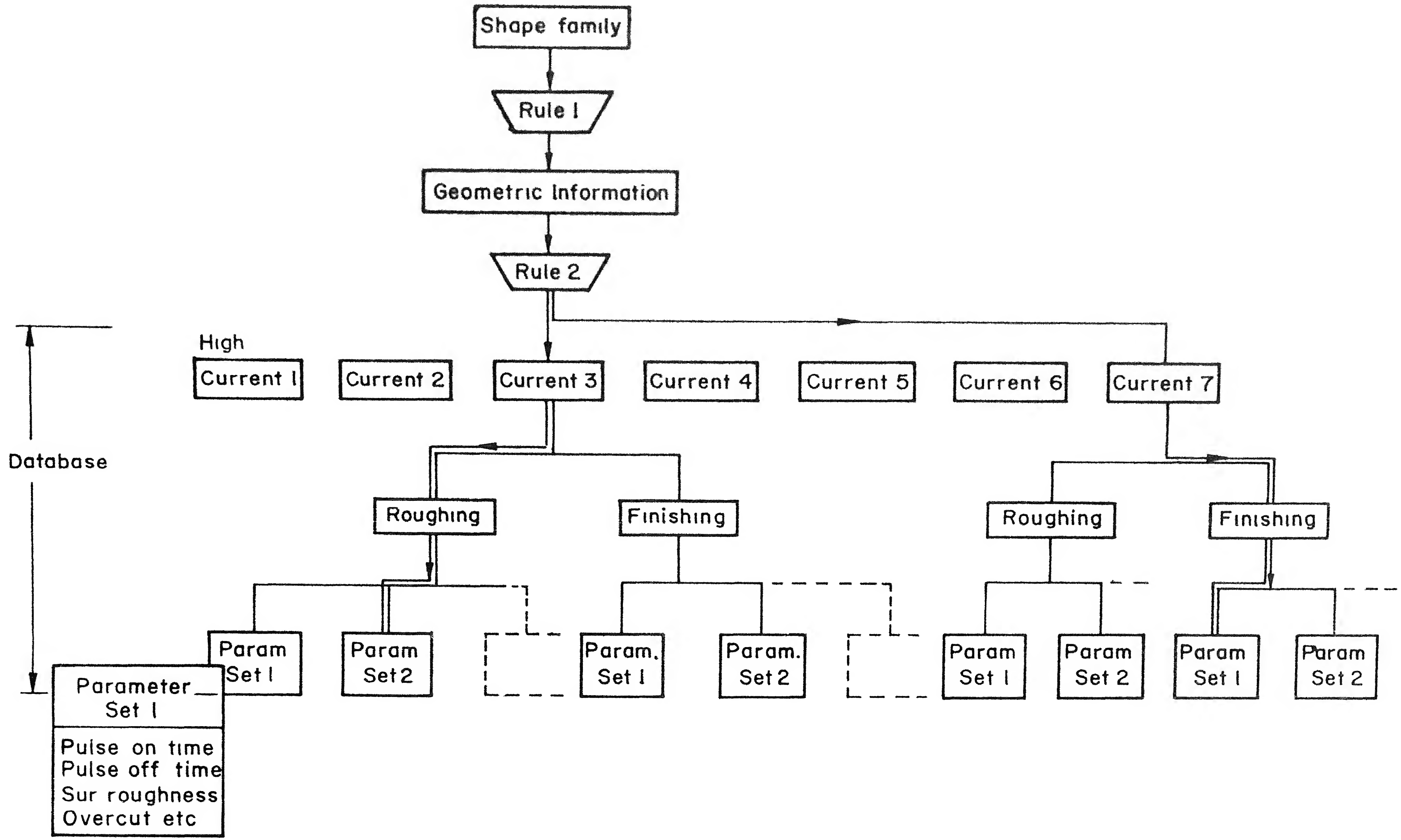


Fig. 3.3 The database structure and inference network for parameter selection.

calculates machining time and average power consumption.

vi Obviously it will be an easy task for the knowledge-base to supply some intermediate set of parameters (for semi finishing etc.) if asked by the user.

The fig 3 3 may clarify the procedure more.

To reduce the size of the database second stage of the chaining is made branched out in two for storing the parameters, one for roughing and the other for finishing. instead of storing those separately.

3.4 : MODULE - FOUR :: OPTIMUM WAVEFORM SELECTION

As mentioned in the previous chapter the aim of this section is to get the waveshape of the "optimum" trapezoidal pulse for an "equivalent" (to recall, pulses giving same removal rate) rectangular pulse, mainly in the semifinishing region. The average height of the rectangular pulse is about 75% of the height of an equivalent rectangular pulse To define a trapezoidal waveshape for a given average height and pulse-width only the 'slope' will be sufficient. So now only problem is to get the accurate value of the slope.

From the various experimental results presented in [1.9], [1.13], and [1.6] all the information of the various optimum waveforms are stored in arrays. Intermediate values are interpolated and then stored in the similar way. Now an array will act as an set of large number of OAV-triplets. Waveshape is the 'object', the characteristics defining its shape is 'attribute' and the 'value' corresponds to the slope value, pulse

width etc

For roughing operation, in which sloped pulses are not-so-advantageous, slope is calculated by some linear functions interpolating experimental data-points over a large range. Surely these values will be not so accurate as above.

3.5 : MODULE - FIVE :: NO-WEAR EDM

As stated earlier, to run the machine in no-wear mode one has to set the multitude of the machine setting parameters according to the technological curves available. (Ref [1.7], [1.14]). Following these curves a database is prepared and prescription appropriate set of parameters is achieved in the similar fashion as the 'parameter selection' module except that, it does not use the 'shape families'.

CE... ...RARY
Acc. No. 115684

3.6 : MODULE - SIX : OPTIMIZATION

Linear programming method has been used for the three optimization problem stated in the previous chapter. Function of the algorithm is described step-by-step as below :

i. Optimization strategies are described to the user so that he can make a choice on them.

ii. After choosing the appropriate strategy, some of the lower and the upper bounds of the variables (generally the machine setting variables : current, on-time etc.) and the general constraints (usually some obtainable work results : overcut , roughness etc.) are to set by the user interactively according to the limitations of his machine and his work requirements.

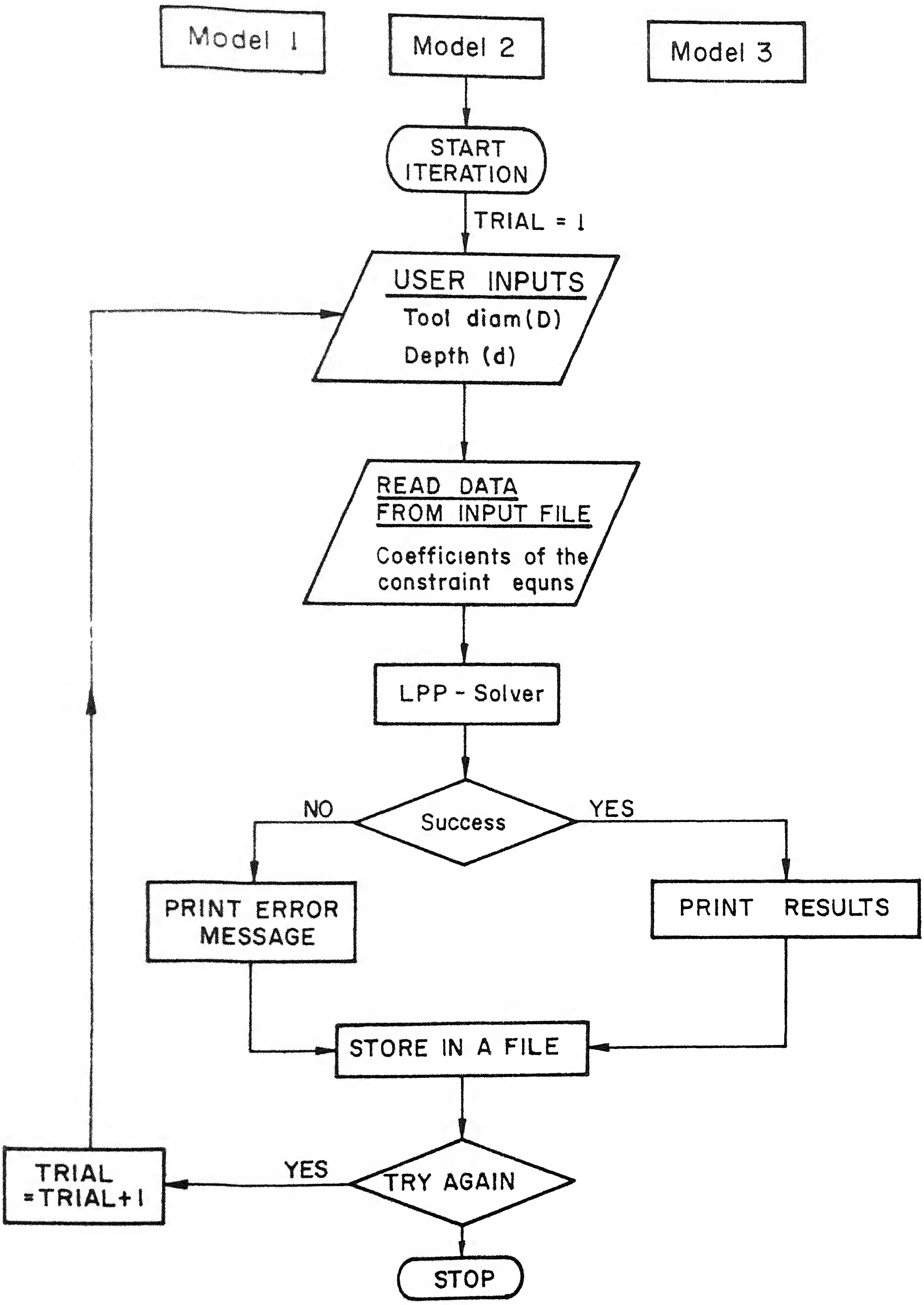


Fig.3.4 Flow-chart for optimization module

iii A LPP-solver will try to find a solution using those bounds. If no feasible solution is found, it will inform the user which constraint is violated

iv For the above case, the user can either relax the bound of the constraint if possible, or otherwise he can change the limits of the variables Clearly, for the latter case he has to have trial and error. As the algorithm shows (fig 3 4) user can run it repeatedly as many times as required All the input and output values and other related information are stored in a separate file as shown in the example in the next section

3.7 : SUMMARY

Architecture of the Expert System is discussed in detail in this chapter First module provides the graphical representation of the shapes, generally machined by EDM Those are 'grouped' to form some families.

Second module applies a new method of knowledge representation for the tool selection, 'equivalent rulebase system', which is much similar to the performance evaluation system for grading the students in a school or university.

Third module, the parameter selection module, uses a large database two-stage chaining if-then rules The functions of the knowledge-base rules and inference engine rules are shown distinctly and also diagrammatically

Fourth module describes the simple rulebase used for selecting an optimum waveform

parameter selection module and not discussed in detail to avoid repetition

Sixth and the final module, optimization, describes the interactiveness and the decision-making capability of the algorithm for optimization It was also clarified that though the module has not used any Expert System tool, it can play a powerful role in the decision-making process for EDM.

Throughout this chapter there was an underlying aim to highlight the concepts of Expert System applied here.

CHAPTER :: FOUR

SYSTEM EVALUATION

Due to increasing commercial interest in Expert Systems a large number of Expert Systems have been developed and put to practical use. The increasing application of Expert Systems in routine tasks and the consequent gradual automation of knowledge intensive task, has led to need for some kind of assurance of the new tool i.e. a need for evaluating the Expert Systems.

The following set of criteria are considered a reasonable basis for expert system evaluation (Ref [2 4]).

o Correctness and accuracy of the final decision : The output from the Expert System should be consistent with the needs of the situation and the criteria for a good solution. In other words, it is the question of whethether the output from the system is valid in the given context Accuracy here means the extent to which the output is satisfactory. Even if the decision is correct in right kind of solution, it may have been inaccurate in specifying the magnitude For example, an Expert System for process control on EDM can have .

if ..

Too many short-circuits

and the value :. 86%

then ..

Prescription ::Servo-reference value to be lowered.

The value :: 4 v

Though the final decision is correct qualitatively but the value may not be so accurate to prevent the short-circuits.

- o Correctness of the reasoning techniques : i.e. whether the internal logic (in the knowledge-base as well as in the inference engine) is consistent with the problem domain and the design of the system.
- o Sensitivity and robustness : It concerns the minimum variation in input needed to change the outcome of the decision. The sensitivity, in fact, is closely related to the efficiency of the system. Robustness refers to the ability to absorb and compensate for the non-standard input. (Inputs may be incomplete, erroneous or contradictory.)

  The system should be sensitive to certain types of input and insensitive to the rest. For a good Expert System a 'garbage in' should result in 'nothing out' rather than 'garbage out' which is often confusing. The system should recognise the 'garbage' and discard it.
- o The quality of the human-computer interaction (communicativeness) : Communicativeness is paramount for the usability of an Expert System. Mainly it requires good user-interface and dialogue quality.
- o Cost effectiveness : It refers to gains from using the system as well as the direct and indirect costs involved in developing and implementing it.

Expert System for a problem domain with large number of uncertainties needs a careful performance evaluation. The inherent randomness of the spark phenomenon in EDM infuses much

uncertainty in the process . After the completion, to ensure validity, the performance evaluation for the system was done in the following manner :

i. Studying carefully a large number of outcomes, the correctness of the final decision was ensured. Clearly.it is more like statistical sampling and it can check out the internal logic also.

ii. As there is no module for process control, the term 'accuracy' (stated before, it bears a special meaning here) is not applicable for this case

iii. By carefully varying the inputs in numerous trial runs the sensitivity was ensured (i.e , the final outcome should not be over-sensitive or reduced sensitive.)

iv. As it is built in Computer Graphics environment, it was comparatively an easy task to make it highly interactive and user-friendly.

v. The system is made robust enough to absorb or to identify erroneous inputs. If the error is easy to detect it will simply print an error message. But if there is any error in intermediate value entry, while it has already started calculation, it will come out and restart the process again. Some simple rules in the inference engine always check the validity of the solution in each step. For an invalid solution, it will not proceed further and start the process afresh.

By ensuring the validation of the system with more rigorous performance evaluation by an EDM-expert it can serve as a powerful commercial Expert System for EDM.

To ascertain the proper functioning of all the features a number of trial had to be made, but a few of them are shown here due to space limitation

4.1 : MODULE - ONE :: TOOL SELECTION

Some selective examples are chosen to give an inside view to the knowledge-base and the reasoning mechanism in this section. (Elaborate explanations, available on the screen, are omitted here).

** Example - 1 **

If ..

Geometric specification ::

Shape family : Ordinary through-hole machining and large block size

Projected machining area (mm^2) : 523.78

Work material :: High carbon steel

Permissible surface roughness :: Abusive (> 12.5)

Tool-life, accuracy, tool-cost preference ::Tool-cost should be minimum .

Then ..

SELECTED TOOL :: BRASS

==================

** Example - 2 **

If .

Geometric specification .:

Shape family . ordinary through-hole machining with large block size

Projected machining area (mm^2) 523.78

Work material : High carbon steel

Permissible surface roughness ·: Roughing (6.3 - 12.5 μs)

Tool-life, accuracy, tool-cost preference :: Accuracy

Then ..

SELECTED TOOL :. COARSE GRAPHITE

================

** Example - 3 **

If ..

Geometric specification ::

Shape family : Sharp edged cavity

Projected machining area (mm^2) : 207.35

Sharpness index : Extremely sharp

Work material :: High speed steel

Permissible surface roughness :: Finishing (1.6 - 3.2 μm)

Tool-life, accuracy, tool-cost preference :: Tool-life

Then ..

SELECTED TOOL :: SILVER TUNGSTEN

===============

** Example - 4 **

If ..

Geometric specification ::

Shape family : Small-hole drilling

Diameter (mm) . 0.225

Work material .: Titanium beta alloy

Permissible surface roughness . Normal (3.2 -6.3 μm)

Tool-life, accuracy, tool-cost preference :: Accuracy

Then

SELECTED TOOL · TUNGSTEN WIRE

note : In the last example as discussed earlier as soon as the diameter is entered less than .25 mm other criteria becomes redundant. (Tungsten wire will be selected always).

4.3 : MODULE THREE :: PARAMETER SELECTION

The database is prepared from the various experimental results published in researchers' handbook and allied publications There may be a considerable discrepancy between the actual and the value prescribed by the system, if the corresponding machining (dielectric flow, open circuit voltage etc.) conditions are not followed. This may not be possible for a given set-up. So particularly validation of this module should be ensured by a number of experimental trial-runs on that machine. Two examples are presented below to clarify the parameter selection procedure :

** Example 1 **

Input ..

Geometric information

Shape family   Ordinary through-hole machining and large block size

Projected machining area (mm^2) :. 523.78

Volume to be removed (mm^3) . 32157.63

Tool . Copper

Permissible surface roughness (micron Ra) .: 15

Average gap voltage ::

For roughing :: 35   For finishing :: 23

Open circuit voltage :: 100

Output ..

	For roughing	For finishing
Current (A)	42.0	6.0
Pulse on-time (μs) ::	150.0	20.0
Pulse off-time (μs) ::	15.0	3.0
Polarity ::	positive	positive
Overcut (mm) ::	0.430	0.085
Final estimation ::		
Surface roughness ::		13.55
Machining time (min) :.	108.74	16.59
Average . Power (W) :.	1225.00	110.4
Average Power at good (90%) sparking condition ::	1091.36	98.4
at poor (40%) condition ::	423.18	38.4

** Example - 2 **

Input :

Geometric information :

Shape family : sharp edged cavity

Projected machining area (mm^2) :: 347.83

Volume to be removed (mm^3) : 9853.60

Sharpness index . moderately sharp

Tool . graphite

Permissible surface roughness (micron Ra) :: 8

Average gap voltage :. For roughing :: 19 For finishing : 12

Open circuit voltage .: 100

Output ::

	For roughing	For finishing
current (A) :	24.0	3.0
Pulse on-time (μs) ::	100.0	5.0
Pulse off-time (μs) ::	35.0	2.0
Polarity ::	positive	positive
Overcut (mm) ::	0.205	0.040
Final estimation ::		
Machining time (min) ::	89.23	10 78
Average Power (W) ::	314.48	24.00
Average Power at good (90%) sparking condition ::	280.70	21.43
at poor (40%) condition .:	111.82	8.57

4.4 : MODULE FOUR :: OPTIMUM WAVEFORM SELECTION

The system has the following limits for the 'equivalent' rectangular pulse :

	For roughing	For finishing
Current :·	15 - 40 A	9 -16 A
Pulse width ::	30 - 100 μs	50 - 80 μs

Example

input..

Process selected .: **semi-finishing**

Rectangular current pulse width (μs) :: 70

Rectangular pulse height (A) :: 12

output ..

Trapezoidal pulse slope (A/μs) :: 0.0932

Trapezoidal pulse width (μs) :: 70.0

Trapezoidal pulse initial height (A) :· 5.85

Trapezoidal pulse final height (A) :: 12.15

4.4 : MODULE FIVE :: NO-WEAR EDM

The maximum current level considered here is 40 A. For large machining area (above 600 mm^2 or so) the prescribed parameters will yield a low metal removal rate. For such cases it is advisable to use the parameter selection module for roughing and then select the parameters for subsequent operations (semi-finishing, finishing etc.) for No-wear mode with the help of this module. Fig 4.10 is quite self-explanatory and it can serve as an example.

4.6 : MODULE - SIX :: OPTIMIZATION

This section uses a LPP-solver from a commercial software library (NAG, available on HP) It is tested with a simple problem on EDM using RC-circuit and was found to give correct results. The solutions of this section can be claimed to be undoubtable unless there is any error in the input datafile or the problem formulation itself Sensitivity clearly depends on the number of general constraints, less constraints means less sensitive. Too many constraints means solution will change drastically for a little change in input and it may move to the infeasible domain To minimize entry error, the algorithm is so constructed that it will not accept any value beyond the prescribed range.

Three output files are shown here .

model - 1

FILENAME · model1.out

Objective function ·: To be minimized .. metal removal rate (mm^3)

Variables :· 2 :: i. pulse-width (μs) ii. frequency (kHz)

General constraints :: 3 :: i. electrode wear rate (mm^3/min)

ii. MRR/EWR (wear ratio)

iii. maximum height of surface roughness (micron)

TRIAL NO = 1

input ..

You_told MINM ON-TIME SETTING (μs) . 100.0

You_told MAXM. ON-TIME SETTING (μs) .. 500.0

You_told MINM. FREQUENCY SETTING (kHz) . 1.00

You_told MAXM FREQUENCY SETTING (kHz) 5.00

You_told MAXM PERMISSIBLE EWR (mm^3) 7800

You_told MINM MRR/EWR RATIO REQD 2 6

You_told MAXM PERMISSIBLE ROUGHNESS (micron) ..20

output ..

** OPTIMUM SOLUTION FOUND **

Solution

On-time = 301.18 MRR = 2.2393

frequency = 5.00 EWR = .7800

MRR/EWR = 2.8863

H = 19.7403

TRIAL NO = 2

input .

You_told MINM ON-TIME SETTING (μs) . 125.0

You_told MAXM ON-TIME SETTING (μs) . 325.0

You_told MINM. FREQUENCY SETTING (kHz) . 1.50

You_told MAXM FREQUENCY SETTING (kHz) 3 00

You_told MAXM PERMISSIBLE EWR (mm^3) .7000

You_told MINM MRR/EWR RATIO REQD. . 2.70

You_told MAXM. PERMISSIBLE ROUGHNESS (micron) :.15

output ..

** NO FEASIBLE SOLUTION FOUND **

Constraint no. violating the bound :: 3

model - 2

FILENAME :: model2.out

Objective function :: To be maximize :: metal removal rate (mm^3/min)

Variables :. 3 .. i. tool diam. (mm)

ii. depth of penetration (mm)

iii. on-time (μs)

General constraints :. 4 :: i. overcut (mm)

ii. surface roughness (micron)

iii. relative electrode wear (REW) (%)

iv. tool wear rate (TWR) (mg/min)

TRIAL NO = 1

You_told MINM. TOOL DIAM. = 20.00

You_told MAXM. TOOL DIAM. = 30.00

You_told MINM. DEPTH OF PENETRATION (mm)= 4.00

You_told MAXM. DEPTH OF PENETRATION (mm)= 6.00

You_told MINM. ON-TIME (μs) = 10.0

You_told MAXM. ON-TIME (μs) = 200.0

You_told MAXM. PERMISSIBLE OVERCUT (mm) = .1000

You_told MAXM. PERMISSIBLE SUR. ROUGHNESS = 2.5

You_told MAXM. PERMISSIBLE REW (%) = 15.0

You_told MAXM. TWR (mg/min) = 5.0

You_told EROSION DIA (mm) = 70.0

You_told EROSION DEPTH (mm) = 10.0

You_told MAXM PERMISSIBLE EWR (%) = 2.2

You_told MAXM PERMISSIBLE SUR. ROUGHNESS (micron) = 20.0

You_told MAXM PERMISSIBLE POWER CONSUMPTION (W) = 5000

output ..

** OPTIMUM SOLUTION FOUND **

Solution :.

Current =	83.15	MRR =	550.03	mm^3/min
On-time =	571.97	EWR =	2.19	%
Off-time =	124.99	SR =	19.99	micron
		POWER =	4041.48	W

4.4 : SUMMARY

To ensure the validity and reliability of the Expert System it has been evaluated by following some well developed guideline, having the following evaluation criteria : correctness of the final decision, sensitivity, robustness, communicativeness etc. The evaluation is based on detailed study of individual cases, few of which are presented here.

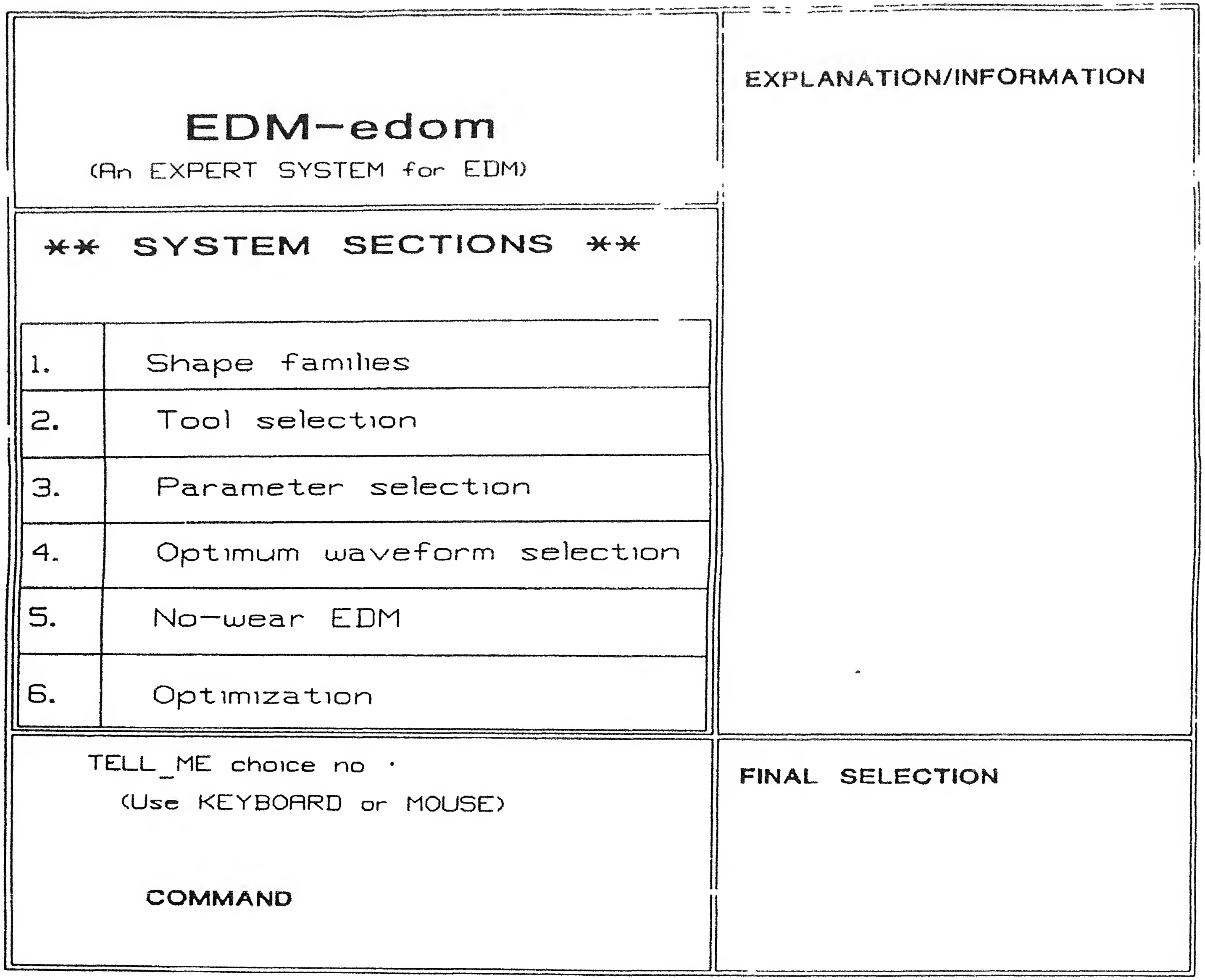


FIGURE 4 1 The main menu

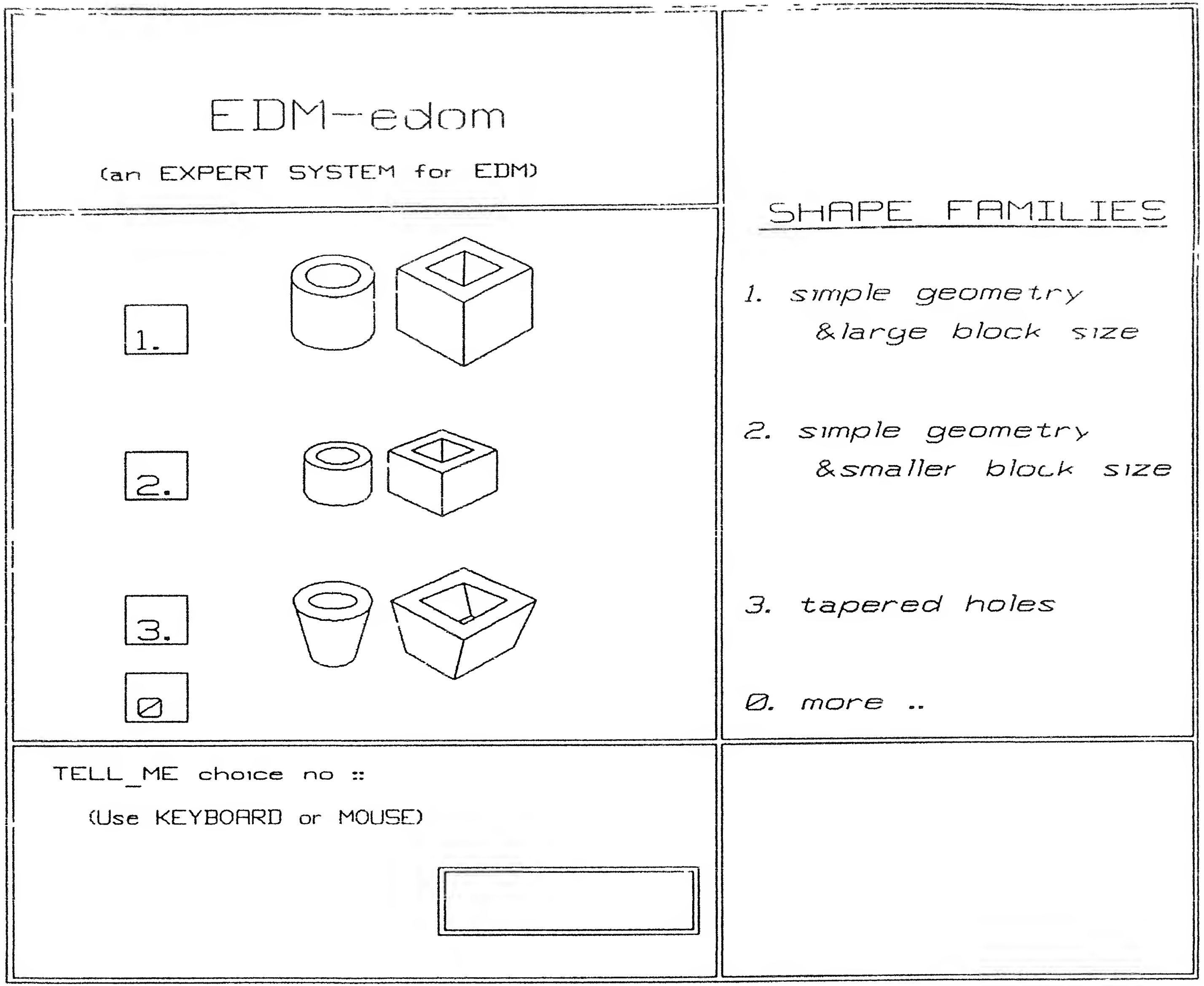


FIGURE 4 2 . Shape families

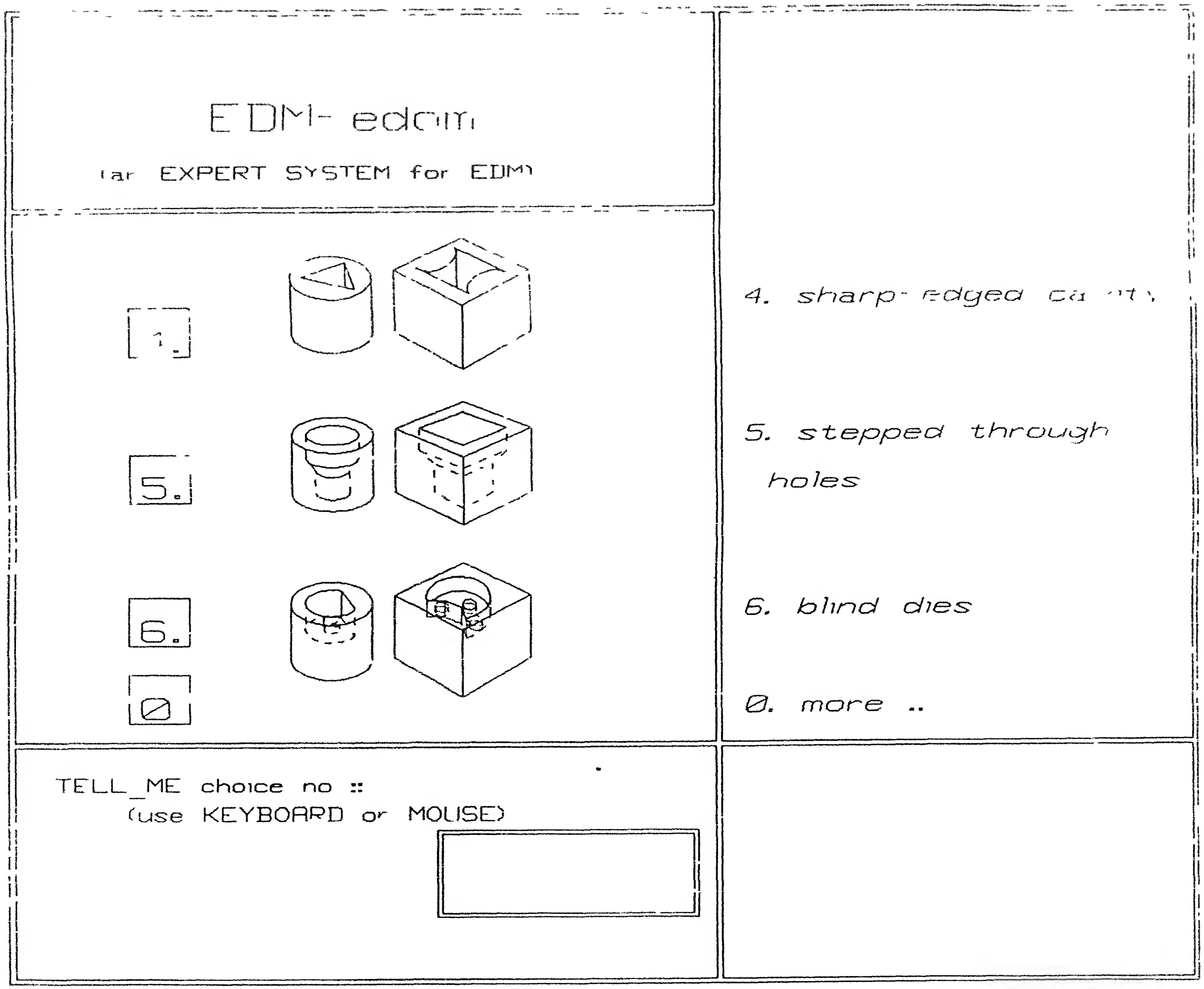


FIGURE 4 3 : Shape families (more)

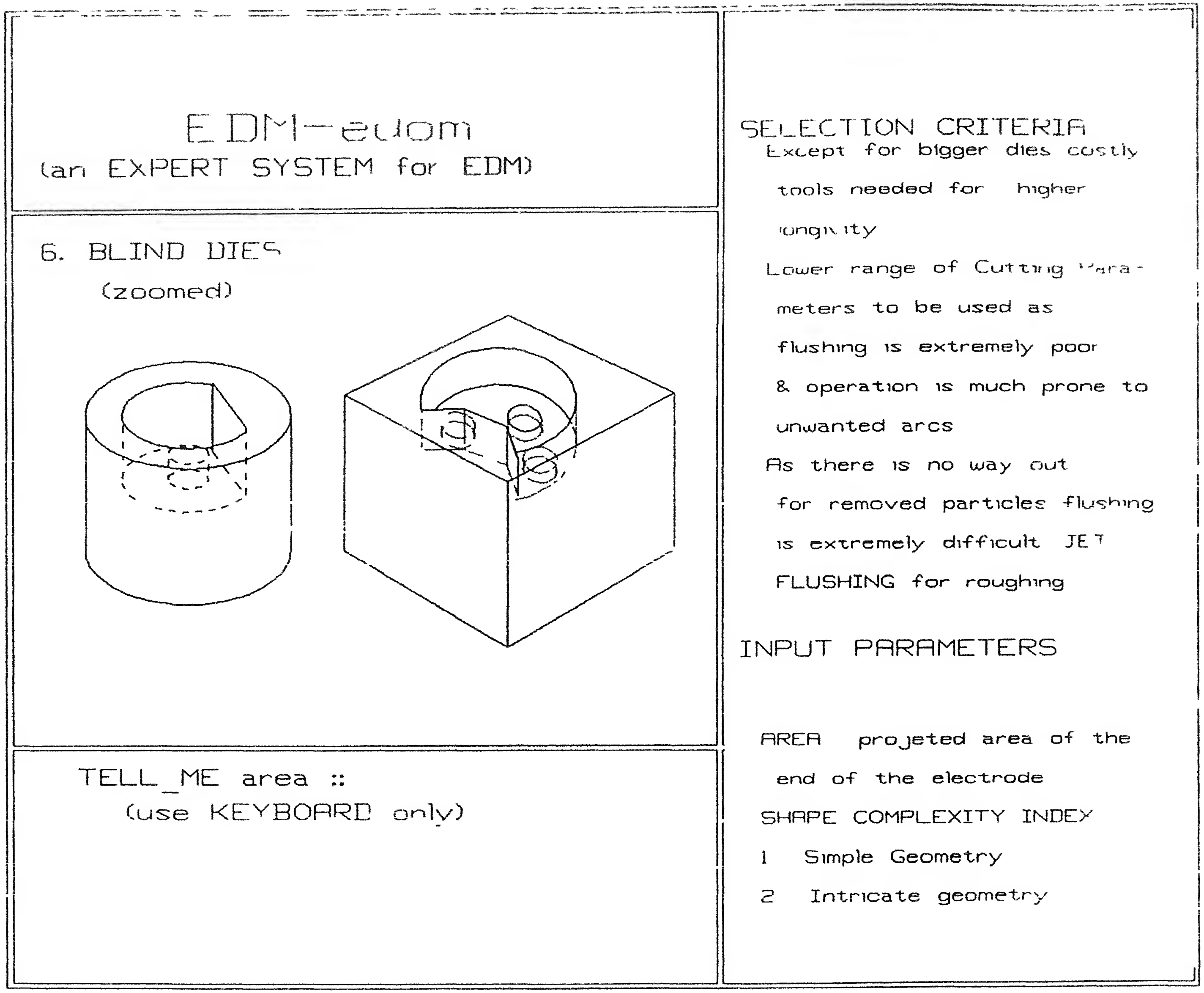


FIGURE 4 4 One selected family

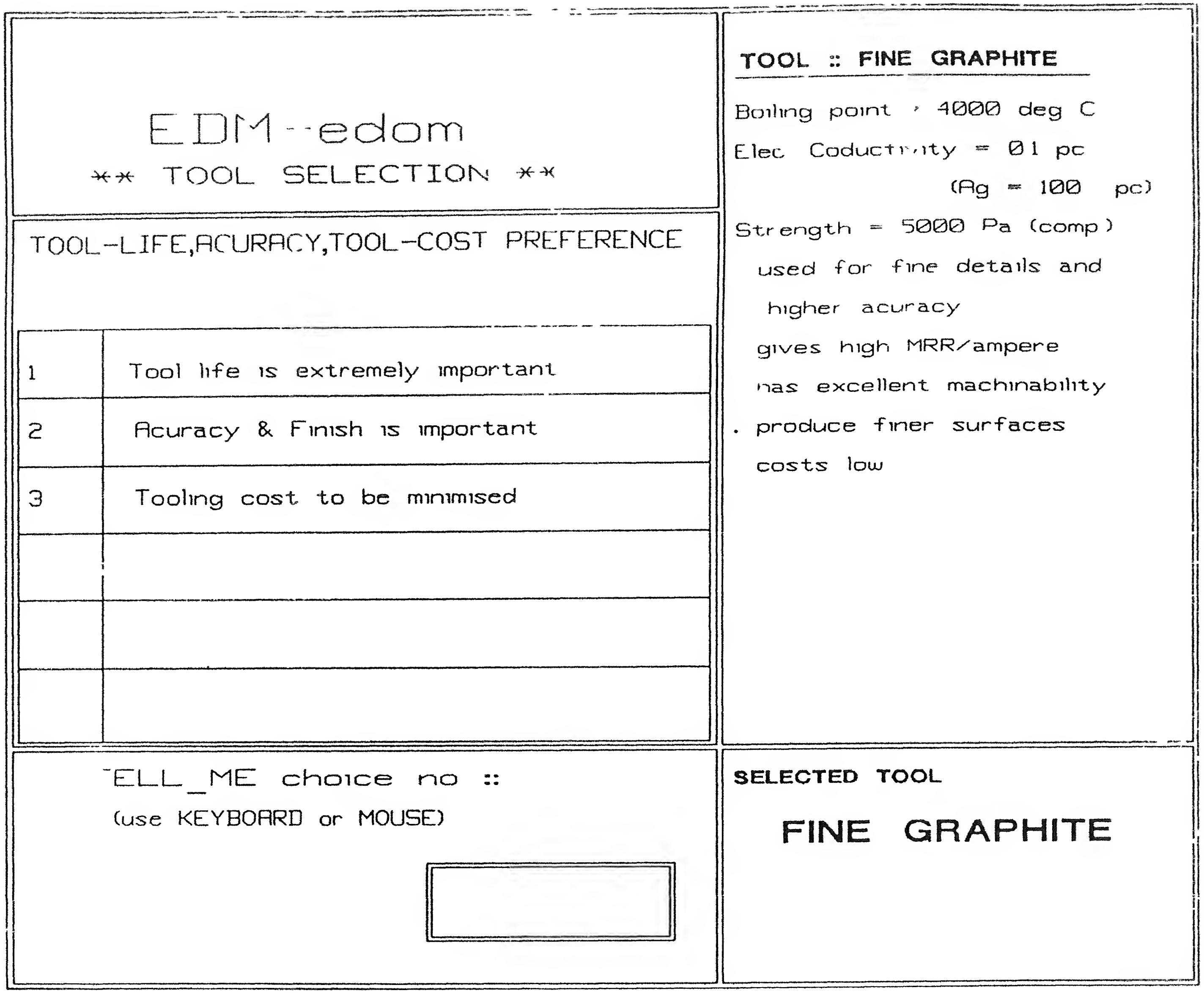


FIGURE 4 5 · Final selection of a tool material

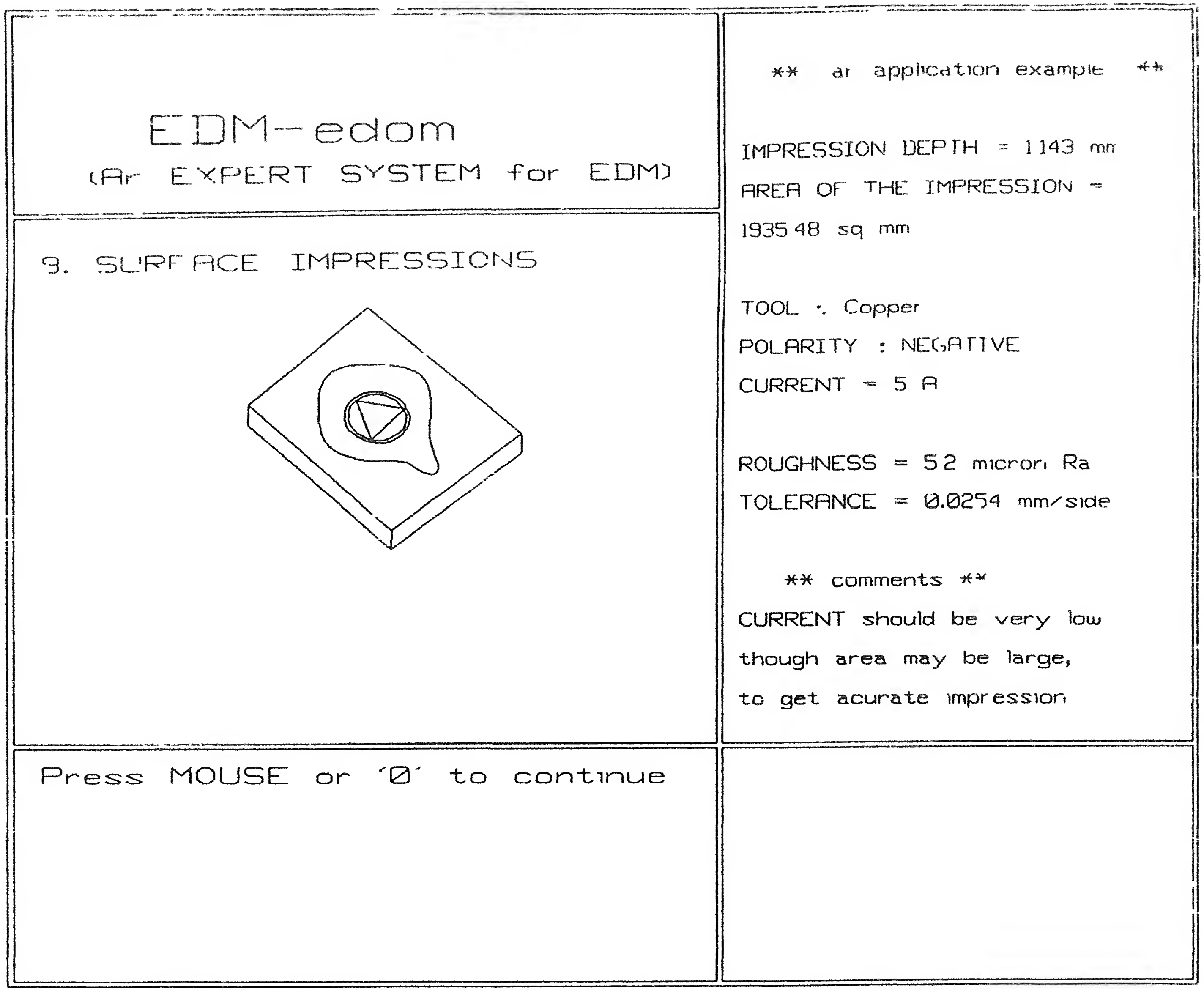


FIGURE 4 6 An application example

******************** Input ********************

AN APPROX. PERFORMANCE ESTIMATION

TELL ME vol to be removed in ROUGHING 1934123 cu mm

(you can estimate it from the working electrode surface area)

TELL_ME vol to be removed in FINISHING 519 56 cu mm

TELL_ME open circuit voltage 100 V

TELL_ME av gap voltage 35 V

******************** output ********************

OVERCUT in FINISHING **0 115** mm

ROUGHNESS (maxm. peak to vally)in FINISHING **4.250** micron

MACHINING TIME in ROUGHING (min) **108 2**

MACHINING TIME in FINISHING (min) . **16.3**

THEORETICAL POWER REQD (W) . (ROUGHING)

1629.31

POWER REQD IN GOOD (90%) SPARKING CONDITION (W)

1604.72

POWER REQD IN POOR (40%) SPARKING CONDITION (W) .

More . **713.21**

** PARF

Press MOUSE or '0' to continue

FIGURE 4 7 Final estimation by parameter selection module

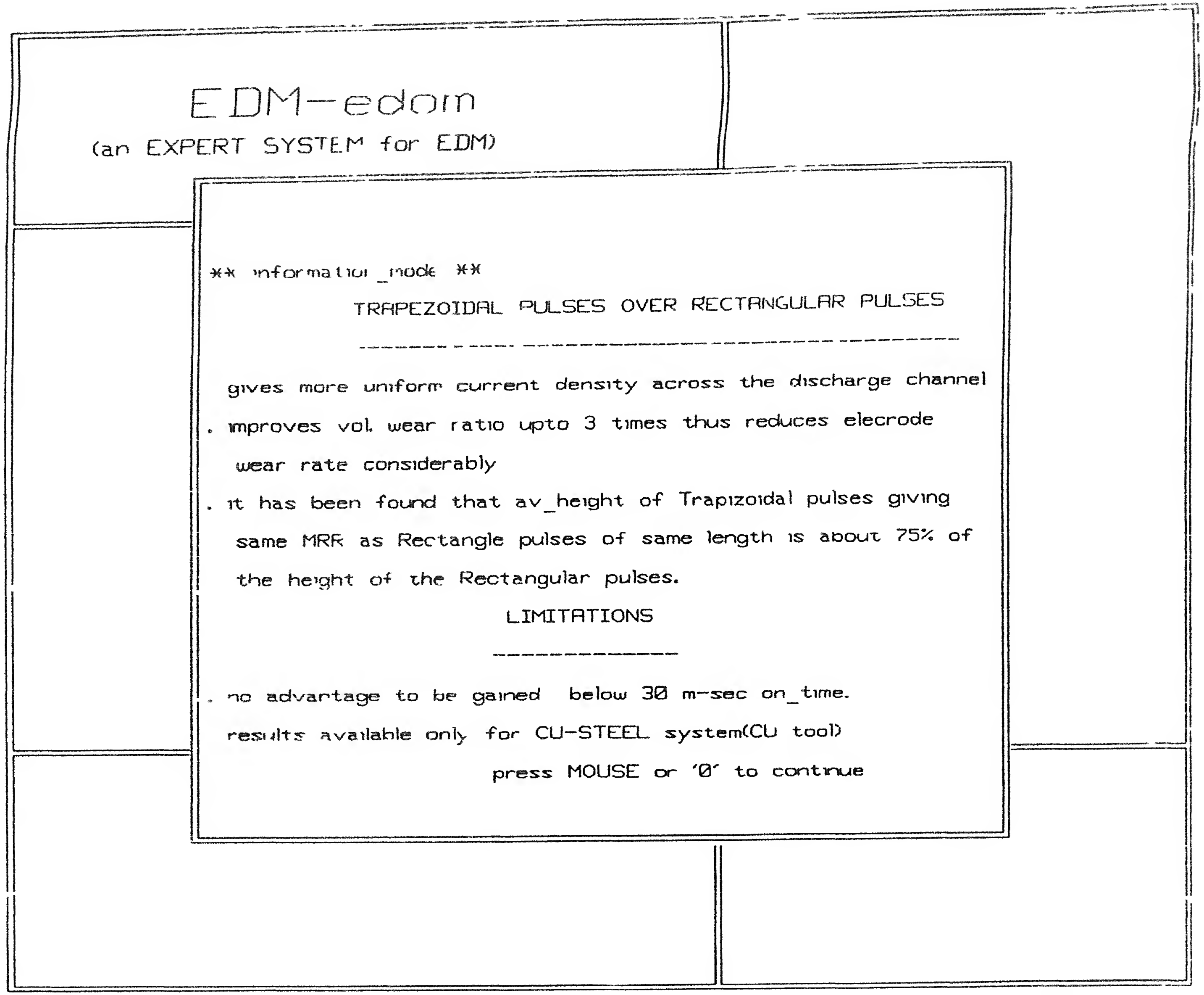


FIGURE 4 8 An example of 'information-mode'

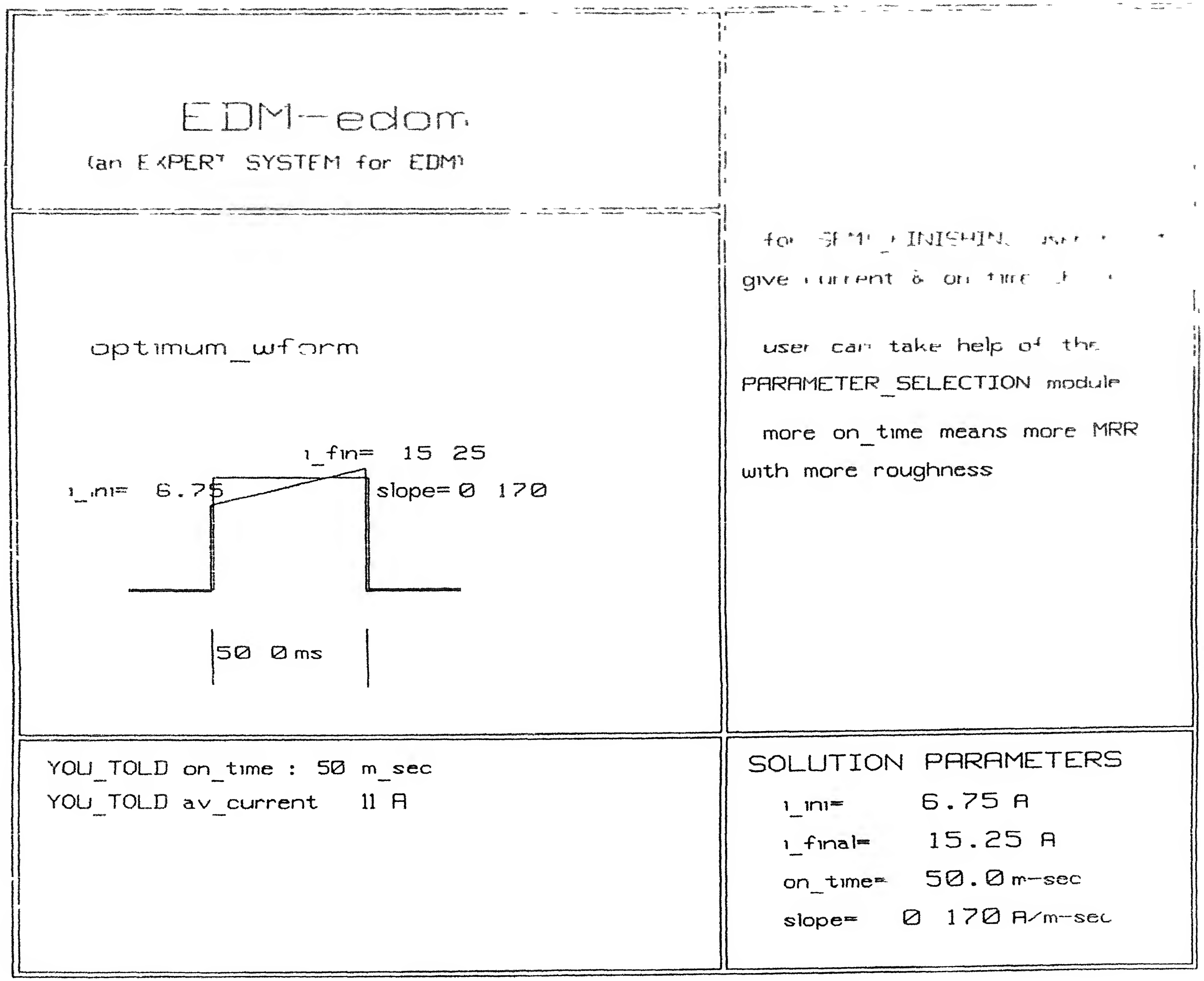


FIGURE 4 9 · Optimum waveform selection . an example

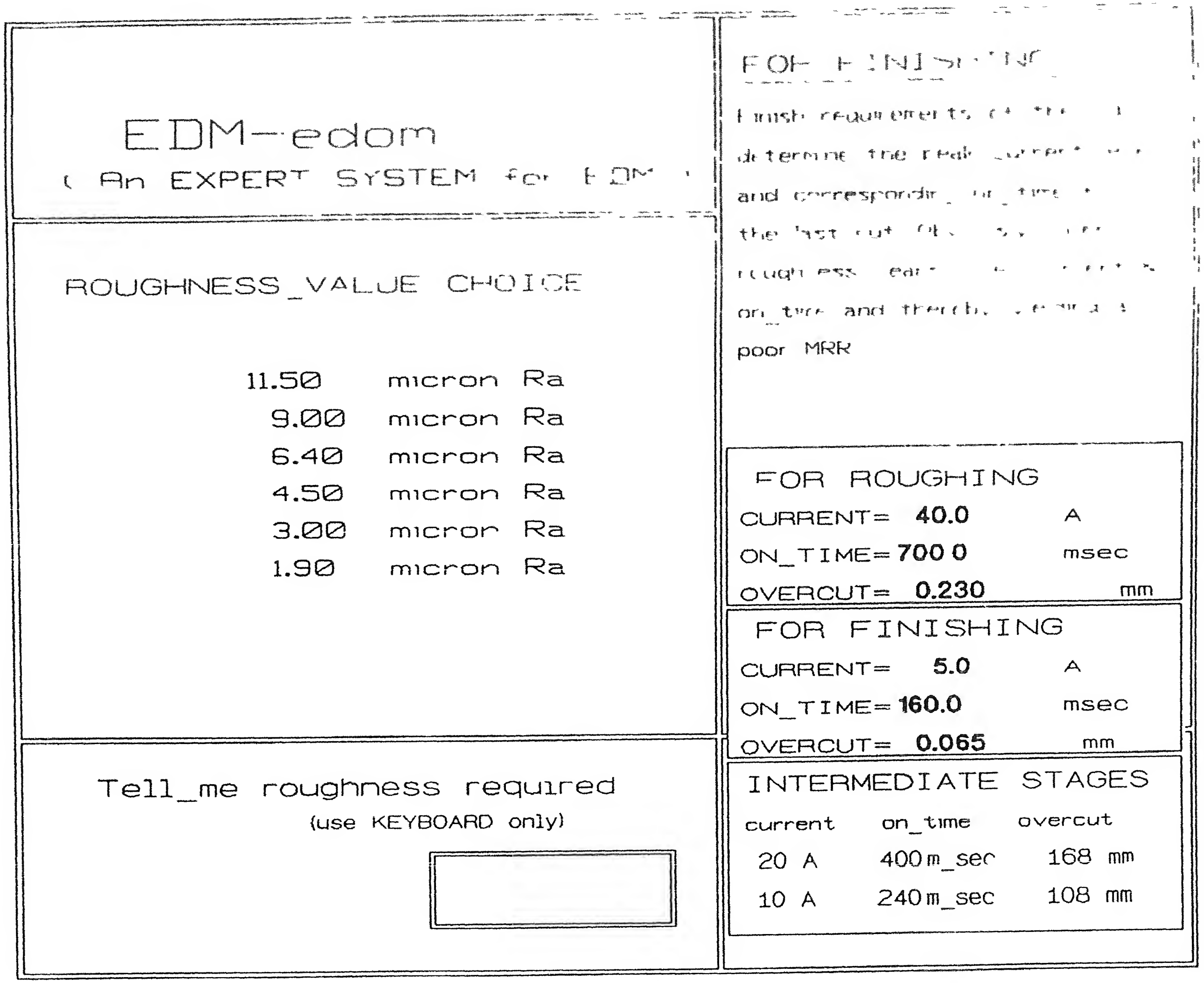


FIGURE 4 10 Parameter selection for No-wear EDM an example

CHAPTER :: FIVE

CONCLUSIONS

Current work shows that knowledge-based Expert System has a tremendous potential to automate the complicated decision-making process for this problem domain, i e., to control the machine parameters of EDM to achieve some desirable results like high metal removal rate, low surface roughness, marginal tool wear etc. Though the recent development of the transistorised control-pulse generator offers a better control over the spark discharge, still now optimum performance is achieved either by highly experienced operator having the necessary knowledge about the technological relationship between the multitude of the setting control of the machine and the obtainable work results or simply by a series of iterative refinements (trial and error). This may be costly in terms of manpower, productivity or the level of technical skill required and ultimately this may restrict the acceptability of the process to grow wider. EDM-edom is an attempt to provide an computer-aid having the following subgoals

- o 'Intelligent' selection of the most appropriate tool material
- o To prescribe an appropriate set of parameters for roughing. finishing and also for intermediate stages if required with an aim to maximize the metal removal rate in roughing and to attain a predetermined level of surface roughness in finishing. Based on these prescribed parameters it also gives the machining time and approximate power consumption.

o The system also deals with some specialized application of the process namely use of non-rectangular pulse and No-wear EDM based on various experimental results, a set of heuristic-based strategies are applied to encapsulate the domain specific knowledge and facts in an usable form.

o Optimization by mathematical tools, though does not belonging to Expert System 'toolkit', is used here to assist the system to compute the 'optimum' set of input parameters needed (theoretically) to achieve a set of desirable results with some constraints on the process

For knowledge representation mainly **rulebase approach** is adopted here as it provides a simple and natural way of expressing the 'captured' knowledge. A new approach was taken to prepare the rulebase for tool selection . tools are 'graded' in different attributes and the cumulative grade is used to arrange the performance hierarchy of the tools. The internal logic or number of rules of remaining the same, the size and execution time of the program can be reduced drastically through this approach. It can handle the 'short-cuts' and the uncertainties in the rules easily For other problems generally the conventional **antecedent-consequent** (having an IF and THEN part) approach is followed

It is built in Colour Graphics environment and it provides an interactive user-interface and picturesque representation.

As a whole the purpose of EDM-edom is conceived to be far-reaching. On the local level, it can readily assist the

it can play a more powerful role where an expert is not accessible. For a more distant approach, it can serve as an aid to the designers or manufactures of EDM to provide a knowledge-base for some special aspects of the process (eg, use of non-rectangular pulses) to improve the effectiveness of the process.

By ensuring the validity with numerous experimental trial-runs on the system by an EDM-expert, it can be made an effective computer aid for EDM and also, can be coupled with a NC-machine head.

SHORTCOMINGS :: FUTURE SCOPE

The shortcomings which provide the scope for future work are pointed out as below :

i. Due to non-availability of information in many cases taken up here, it has a narrow application range. (All the limitations are stated in earlier chapters.)

ii. The backward chaining for explaining the entire decision-making process or to clarify the rule used as a whole, though felt essential, is not provided. Here more emphasis was given on capturing the related expertise and preparing the knowledge-base.

iii. The module, naming 'Shape Families' can be further improved to have a more conforming and self-defining classification of the workpiece. (Many decisions here are left to the user.)

iv. Unfortunately, no cost estimation is done for the system.

From the beginning of the development of the system it is so constructed that it is absolutely flexible to have "horizontal" as well as "vertical" expansion i.e., knowledge-base of individual module can be extended 'horizontally' or 'vertically', a separated module can be added for some other specific task on EDM

REFERENCES

On EDM

[illegible] Non-traditional Manufacturing Process, [illegible] New York, 1987 pp 208-245

[illegible] A., New Technology, The Intitution of Engineers [illegible] 1977 pp 173-180

[illegible] S.K., El-Menshawy, M F, "A correlation [illegible] machining parameters and machinability in EDM",

[1.4] [illegible] J R, "A Basic Analysis of Pulse Trains in [illegible] Discharge machine", Int J Mech Tool Des Res [illegible] 1982 pp 199-213

[illegible] H E, "Slope Control A Great Improvement in [illegible], Annals of the CIRP vol 18 no 1, 1970

[illegible] Comparision of var[illegible] Erosion System with [illegible] and Trapezoidal Pulseforms" Annals of the [illegible] 1980 pp 103-106

[illegible] Wick, Tool and Manufacturing Engineering [illegible] Fourth Edition, 1983, pp 14.12-14 58

[1.8] [illegible] "Effect of Materials on the Mechanism of EDM", [illegible] Engg Matls & Technology · Trans. of ASME vol 105, [illegible] pp 132-137

[1.9] [illegible] J, Crookall, J.R., "The Effectiveness of Non-rectangular Current Pulse Forms in EDM", Proc. of 19th Int MTDR Conf., 1978, pp 551-562

[1.10] George [illegible] Philip, P.K, "Analysis of EDM Parameters and Tool Wear in Cu-DIE Steel System, Proc. of 8th AIMTDR, 1978

[1.11] Gurumurthy, T., Aravind, B.M, "Development of a Databank for Electro-Discharge Machine", 12th AIMTDR Conf., Tata McGraw-Hill Pub Co Ltd 1986, pp 512-516

[1.12] Jeswani, M L, "Small Hole Drilling in EDM", Int J Mach Tool Des Res. vol 19, 1984, pp 165-169

[1.13] Jilani, S.T., Pandey, P.C., "Metal Removal in EDM using Non-rectangular Current Pulse Forms", Proc of the 11th AIMTDR, 1984, pp 292-297.

[1.14] Machining Data Handbook, 3rd Edition vol 2, Compiled by Technical staff of Machinability Data Center, Metcut Res. Asso Inc., Cincinnati, Ohio, 1987, pp 12.15-12 46

[illegible] Methods of Machining, Chapman and

[1.16] Mukherjee [illegible] Sanyal, S K, "Multi-objective Optimization of EDM [illegible] Contrast Intensity of Information" [illegible] AIMTDR [illegible] 1982 pp 321-324

[1.17] [illegible] "Electric Discharge Machining with [illegible] electrode" Bul of Japan Soc. of Prec Engg [illegible]

[1.18] [illegible] J. Zajac, J "An Approach to Identification [illegible] Multi-criterion Optimization of Electric Discharge Machining Process" Proc of thw 23rd Int MTDR Conf [illegible]

[1.19] Operating [illegible] for Electric Discharge Sinking Machine, [illegible]

[1.20] Production Technology, H M T pp 459-476

[1.21] [illegible] R [illegible] Snelissen, H, "Correlation between Electric Discharge Machining Data and Machining Setting", Annals of the CIRP vol 24 no 1, 1975, pp 83-88

[1.22] Srinivas[illegible] A "Multi objective Optimization of EDM Process", [illegible] vol [illegible] 1990, pp 33-37

On Expert System

[2.1] Alty, J [illegible] "Expert System Building Tools" Topics in Expert System Design, N Holland, 1989, pp 181

[2.2] Balachandran M, Gero, J S, "A Model for Knowledge Based Graphical Interfaces", Artificial Intelligence Developments and Applications N Holland, 1988 pp 147

[2.3] Boose J H, "ETS . A System for the Transfer of Human Expertise", Knowledge Based Problem Solving, Prentice-Hall, New Jercy, 1986. pp 68

[2.4] Hollnagel, E, "Evaluation of Expert Systems", Topics in Expert System Design, N Holland, 1989, pp 377

[2.5] Ignizio, J P, Introduction to Expert Systems, McGraw-Hill, New York 1991

[2.6] Jardine, T J, "A Machinability Knowledge Based System", Knowledge Based Problem Solving, Prentice-Hall, New Jercy, 1986, pp 257

[2.7] Kulikowski C A, "Knowledge Base Design and Construction From Prototype to Refinement", Topics in Expert System Design, N Holland, 1989, pp 145

[2 8] Moore R L , "Expert System in Process Control : Application Experience", Application of Artificial Intelligence in Engg Problems, vol.1, Springer-Verlag, Berlin 1986 pp 21

[2 9] Prerau D S 'Choosing an Expert System Domain", Topics in Expert System Design, N.Holland, 1989, pp 27.

[2 10] Rich, E Artificial Intelligence, McGraw-Hill Book Company, Singapore, 1990

[2 11] Taylor, W A , 'Development of a Knowledge Based System in Arc Welding", Application of Artificial Intelligence in Engg Problems vol 1, Springer-Verlag, 1986 pp 549.

APPENDIX

[illegible] the [illegible] following experimental data an useful relationship between the [illegible] ected area of the electrode and the maximum [illegible] established

Observation 1:

[illegible] (Ref [4.44]) says 'The physical size of the [illegible] determines the amount of amperes an electrode can draw. For instance, a [illegible] 12 mm dia electrode can draw only 3 A, whereas a [illegible] 4 mm diam electrode may be able to draw 50 A".

From this information, a relationship is proposed as :

The maximum permissible current (I_{max}) = $2.2116 \, (Area)^{0.5}$. (A.1)

The proposed relation is validated from the following observations mentioned below. It has been found that nowhere the maximum current (computed as above) is exceeded, and usually 70-95% of the maximum is used for roughing operation.

Observation 2: Ref [1.3]

Electrode diam = 40 mm

Maximum current used (I) = 70 A

I_{max} computed from the relation A.1 = 78.4 A

I = 89.3 % of I_{max}

Observation 3: Ref [1 10]

Electrode dia [illegible] mm

Maximum current used (I) = 50 A

I_{max} computed from the relation A 1 = 58 8 A

I = 8[illegible] % of I

Observation 4: Ref [1 18]

Electrode diam. = 70 mm

Maximum current used (I) = 1[illegible]5 A

I_{max} computed from the relation A 1 = 131 3 A

I = 95 % of I_{max}

Observation 5: Ref [1.14] (pp 12 44)

Electrode area = 161 29 mm^2

Maximum current used (I) = 25 A

I_{max} computed from the relation A.1 = 28.1 A

I = 89 % of I_{max}

Observation 6: Ref [1 10]

Electrode dia = 30 mm

Maximum current used (I) = 50 A

I_{max} computed from the relation A 1 = 58.78 A

I = 85 % of I_{max}

A11..81

ME-1993-M-DEV-IDM